FARWELL

The Corona Produced by Continual Potentials

Electrical Engineering

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THE CORONA PRODUCED
BY CONTINUOUS POTENTIALS

BY

STANLEY PRINCE FARWELL
B. S. University of Illinois, 1907
M. S. University of Illinois, 1910

THESIS

Submitted in Partial Fulfillment of the Requirements for the

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IN

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THE GRADUATE SCHOOL

May 15, 1914.

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

STANLEY PRINCE FARWELL

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TABLE OF CONTENTS

Page

Part I

Introduction

Chapter I The Direct Current Corona 1

Section 1 Nature of the Corona and Previous Work 1

Section 2 Object of the Investigation 6

Chapter II Generating Apparatus and Instruments 7

Section 1 Set-up of Apparatus 7

Section 2 Instruments and Calibrations 11

Chapter III Preliminary Experiments 16

Part II

Experimental Investigation

Chapter IV Characteristic Curves at Atmospheric Pressure 20

Section 1 Preliminary Remarks 20

Section 2 Method of Conducting Tests 22

Section 3 Variation of Critical and Glow Voltages 24

Section 4 Variation in Nature of Corona 25

Section 5 Discussion of Characteristic Curves 26

Chapter V Factors Affecting Coronal Current 51

Section 1 Pressure 51

Section 2 Condition of Air 64

Section 3 Moisture 64

Section 4 Temperature 71

Section 5 Material of Wire 71

Section 6 Magnetic Field 74

Chapter VI Pressure Due to Ionization 75

290511

Page

Chapter VII Discontinuous Brush Discharge 79

Chapter VIII Effect of Short Arc Upon Discharges 94

Chapter IX Corona between Parallel Wires 97

Section 1 Phenomena at Reduced Pressures 97

Section 2 Phenomena at Atmospheric Pressures 99

Section 3 Exploration of Field 101

TABLES

Number		Page
1	Wire Diameter 0.027 mm.	27
2	Wire Diameter 0.037 mm.	28
3	Wire Diameter 0.046 mm.	30
4	Wire Diameter 0.052 mm.	32
5	Wire Diameter 0.077 mm.	34
6	Wire Diameter 0.077 mm.	36
7	Wire Diameter 0.135 mm.	37
8	Wire Diameter 0.24 mm.	39
9	Wire Diameter 0.26 mm.	41
10	Wire Diameter 0.41 mm.	43
11	Wire Diameter 0.65 mm.	45
12	Wire Diameter 0.77 mm.	46
13	Tests Wire Diameter 1.02 mm. and 1.28 mm.	47
14	Glow Voltage and Radius	49
15	Critical Voltage and Pressure 0.41 mm. Wire	52
16	Temperature and Current 0.135 mm. Wire	72
17	Effect of Pressure - 0.41 mm. Wire	54
18	Effect of Pressure - 0.135 mm. Wire	57
19	Characteristic Test, 760 mm. for 0.052 mm. Wire	60
20	Condition of Air and Current Test	65
21	Effect of Pressure - 0.077 mm. Wire	62
22	Effect of Moisture - 0.077 mm. Wire	67
23	Pressure Due to Ionization	77
24	Characteristic Curve - 0.26 mm. Wire	80
25	Data on Photographs of Corona	83
26	Characteristic Test - Parallel Wires	100
27	Distribution of Field Between Parallel Wires	104

FIGURES

Number		Page
1	Photograph of Laboratory	9
2	Diagram of Connections	10
3	Tube for Characteristic Tests	21
4	Characteristic Curves: Wire Diameter 0.037 mm.	29
5	Characteristic Curves: Wire Diameter 0.046 mm.	31
6	Characteristic Curves: Wire Diameter 0.052 mm.	33
7	Characteristic Curves: Wire Diameter 0.077 mm.	35
8	Characteristic Curves: Wire Diameter 0.135 mm.	38
9	Characteristic Curves: Wire Diameter 0.24 mm.	40
10	Characteristic Curves: Wire Diameter 0.26 mm.	42
11	Characteristic Curves: Wire Diameter 0.41 mm.	44
12	Characteristic Curves: Wire Diameters 0.65, 0.77, 1.02, 1.28	48
13	Glow Voltage and Radius Curve	50
14	Glow Voltage Pressure Curves, 0.41 mm. Wire	53
15	Temperature and Current, Wire Diameter 0.135	73
16	Effect of Pressure: Wire Diameter 0.41 mm.	55
17	Effect of Pressure: Wire Diameter 0.052 mm.	61
18	Effect of Pressure: Wire Diameter 0.077 mm.	63
19	Effect of Moisture: Wire Diameter 0.077 mm.	69
20	Voltage-Ionization Pressure Curve	78
21	Tube for Corona Photographs	80
22	Corona Photographs - Pressure & P.D. Varied	86
23	Corona Photographs - Pressure & P.D. Varied	87
24	Photographs - Negative Discontinuous Discharge	88
25	Photograph - Discharges at Higher Pressures	89
26	Photographs: Variation of Negative Discontinuous Discharge with P.D.	90

FIGURES continued

Number Page

27 Negative Discontinuous Discharge with P.D. . 91

28 Characteristic Curve for Negative Discontinuous Discharge 92

29 Number of Brushes and Current per Brush as Function of P.D. 93

30 Photographs: Effect of Short Arc 96

31 Tube for Parallel Wire Tests 99

32 Photographs: Corona Between Parallel Wires 98

33 Field Distribution Between Parallel Wires 105

PART I

INTRODUCTION

--Chapter I--

The Direct Current Corona

Section 1: The Nature of the Corona and Previous Work.

In alternating-current transmission lines at very high voltages a loss occurs by dissipation of power into the air. This is accompanied by luminosity of the air surrounding the conductors and to this glow the name corona has been given. Loss begins at some critical voltage, depending on the size and spacing of the conductors, etc., and increases very rapidly above this voltage. This corona effect is of considerable importance as it involves a power loss of some magnitude on long lines and it has been studied by Scott, Ryan, Mershon, Jona, Peek, Whitehead and others.

The corresponding direct current case, although not of such immediate importance, is yet of considerable interest in view of the high-tension direct current developments on the Continent of Europe. The only work of much importance along this line has been done by Watson[1] and Schaffers[2]. Watson has carried out a number of tests of wires strung axially along a cylindrical tube and also on two parallel wires out-of-doors. The wires used varied

---

1) Watson, Electrician-London. Vol. 63, 1909., p.828.
Vol. 64, 1909-10, pp.707 & 766.

2) Schaffers, Comptes Rendus, July 1913, p.203.

by gradually increasing diameters from 0.70 mm. to 12.76 mm. The source of power was an influence machine of special design and large output and would give any potential required up to 70,000 volts. The arrangements for his tests and the terms commonly used in connection with the theoretical discussion of the corona can be brought out by a quotation from his paper of Sept.1909:

"The wire was enclosed in a galvanized-iron cylinder 8 in. in diameter and 6 ft. long, which could be exhausted of air by means of a small motor-driven pump. The degree of humidity of the air was also under control. Experiments would be made at various pressures from atmospheric down to 350 mm.

The use of a wire in a concentric cylinder, although not representing the actual conditions of a transmission line, is yet very convenient when it is desired to have various factors under control. It possesses, moreover, the advantage that considerably lower pressures (less than half) are required to produce the same electric stress around the wire.

Theoretically, the critical voltages for a wire in a cylinder and two parallel wires have a direct ratio, which can be calculated when the dimensions of the wires, cylinder, and spacing are known.

The expressions for obtaining the electric stress at the wire are as follows:-

Wire in cylinder.

$$R_{max.} = \frac{V}{a \log_e \frac{b}{a}}$$

Two wires:-

$$R_{max.} = \frac{V}{2a \log_e \frac{d}{a}} \left(1 + \frac{a}{d} \right)$$

where V = P.D. between wires,
a = radius of wire,
d = distance apart of wires,
b = radius of cylinder.

Of these formulae, the first is exact, while the second is only approximate, but is very nearly correct for all ordinary cases where a is small compared to d, and the wires are well above the earth".

The value $R_{max.}$ in the above formulae is called by some writers the "critical surface intensity" and is extensively used in expressing the results of tests. It has been well established by Watson and others that this critical surface intensity increases very greatly as the radius of the wire decreases. A comparison made by Whitehead of his results for this intensity in the case of alternating potentials with the similar values deduced by Watson for continuous potentials shows that for a given size of wire it requires the same voltage to produce corona in both cases, if the maximum value of the alternating potential be used.

The appearance of the positive and negative coronae are described by Watson as follows:-

"Wire in cylinder: As was to be expected, some difference was found to exist between the case where the wire was positive to the cylinder and when it was negative to it, these differences occuring both in the appearance of the corona and in the measurements relating to it.

When the wire was positive to the cylinder, it appeared, if viewed in a subdued light, to be surrounded with a thin luminous film. If viewed in complete darkness, under certain conditions the space surrounding the wire for a distance of 1 cm. or

2 cm. radially was seen to be full of fine branching bluish purple brushes, darting about all the time and never remaining stationary on any point. The discharge made a slight hissing noise.

When the wire was negative the luminous film was absent, but the wire was surrounded by a halo consisting of short straight reddish-colored discharges about 3 to 5 mm. long, practically stationary and much brighter than the corresponding positive discharge. This discharge was accompanied by a loud hissing noise plainly audible above the hum of the motor and the influence machine.

The negative corona was greatly affected by the presence of particles of dirt upon the wire. If the wire was dirty the discharge seemed to concentrate itself upon the particles of dirt, from each of which a bright tuft of reddish light emanated not much longer, however, than the previous brushes from the clean wire. The discharge was much less noisy, and, in fact, if the wire were dirty enough, nearly silent."

The article by Schaffers referred to above, gives the results of a study of the ionization in cylindrical fields, using wires of various diameters ranging from 0.0006 cm. to 0.70 cm. in tubes ranging from 1.70 cm. to 11.7 cm. in diameter. He says nothing of the source of potential used or of the appearance of the coronae. He finds that for the larger size wires the positive corona appears at a lower voltage than the negative and that for the smaller sizes, the reverse is true, the radius 0.01 cm. separating these two regions. Another conclusion reached by this investigator is that the nature of the material of the wire is without effect upon the coronal voltage, at least if the wires are not very fine.

A recent paper on "Theory of the Corona" by Bergen Davis (Proc. A.I.E.E. April 1914, p.529) contains the only attempt thus far published to adequately explain the physical laws governing the formation of corona. His method of attack upon this problem may be summarized in the following published abstract of his paper:

"The theory of the corona developed in this paper explains the coronal discharge by the application of the known laws of the discharge of electricity through gases.

The experiments of Dr.Whitehead and Mr.F.W.Peek and others have shown that the surface gradient X_s at the surface of a smooth wire necessary to start the corona increases very greatly as the radius of the wire decreases. As an illustration of this increase it is found that the coronal gradient X_s at the surface of a wire 0.5 cm. radius is 46,000 volts per cm., while a gradient of 97,000 volts per cm. is required for a wire of 0.02 cm. radius. The phenomenon is due to ionization by impact. The ions n_o move in toward the wire from the place at which they cross a region where the gradient is X_o = 26,600 volts per cm. up to the wire. They produce other ions, and n ions arrive at the wire. The condition for the corona is that n shall be a constant. If α = the number of ions that one ion produces in a cm., then

$$n = n_o e^{\int_a^b \alpha \, dx}$$

The α is a function of X at every point. This function is expressed in terms of x. It is introduced into the above equation, and on integration the equation for the corona is obtained. The equation also contains a term for the density of the air. The equation thus takes account of changes of pressure such as altitude

and temperature effects. The equation when plotted in a curve for the variation of X_s with the radius of the wire, agrees with the experimental results of Peek and Whitehead with as great accuracy as the experimental results would warrant."

Section 2: Object of the Investigation of the Corona.

A considerable amount of work has been done on the loss of power due to the formation of the corona in high-tension transmission lines. The phenomena have been studied exhaustively from the technical standpoint; but the real physical laws have not yet been discovered, except that we know that the corona is connected with the ionization of the air.

The object of this thesis was to discover the underlying physical laws. It was necessary, however, before the theoretical problem was attacked, to extend the measurements with smaller wires and reduced pressures, to investigate the distribution of the field, and to measure the velocity of the ions. This experimental part lead to so many new effects and phenomena that it seems premature to form final ideas on the mechanism of the phenomenon.

--Chapter II--

Generating Apparatus and Instruments

Section 1: Set-up of Apparatus.

The source of the continuous potentials employed in this investigation was a battery of small continuous current generators connected in series. There were thirty of these, each rated as follows:

Continuous Current Generator.
Amp. 0.5. Spec. 260391.
Watts 250. Speed 1700.
Volts 500. Shunt Wound.
General Electric Co.

The potential available, then, was 15,000 volts when the machines were run at normal voltage.

These generators were arranged in two sets, one of twenty machines and the other of ten. The first set consisted of two parallel and adjacent rows of ten machines each, the rows being made up of machines connected end to end by flexible couplings, and both rows being driven by a five horse-power direct-current motor. The generators were self-excited and could be put into service by closing a small knife-switch in each field circuit. Voltage control was obtained in this manner and by controlling the speed of the set by field control of the motor. A fine adjustment of voltage was obtained by means of a rheostat in the field circuit

of one of the generators. The series connection between the machines was permanent. The second set consisted of ten machines separately belt-driven from a line shaft belted to a five horsepower shunt motor. These machines were controlled by single-pole double-throw knife switches so wired that when the blades were down, the fields were short-circuited. By throwing the blades up the fields were excited. The series connection between these machines was also permanent. Voltage control of this set was obtained by the switches and by a rheostat in the field of one of the generators.

The apparatus used and its arrangement are shown in Figs. 1 and 2. The numbers on the photograph indicate the following apparatus:

1) Generating Set #1. Set #2 in background.
2) Knife Switches for Field Control.
3) Field Rheostat-Set #2.
4) Line Switch. Brass Contact Weight, Mercury Cup.
5) U-Tube Water Resistance for Protection of Instruments.
6) Positive Bus-Bar. #10 Copper. Connected to 5).
7) Negative Bus-Bar. #10 Copper. Grounded on Water-Pipe.
8) Kelvin Electrostatic Voltmeter.
9) Electrostatic Voltmeter by Max Kohl, Chemnitz.
10) Switch for Connection of Corona Apparatus.
11) Pole-changing Switch. Mercury Cups in Paraffine.
12) Corona Apparatus.
13) Mechanical Air Pump.
14) Mercury Air Pump.
15) Drying Apparatus. Soda-lime Tube. H_2SO_4 Wash-bottle.

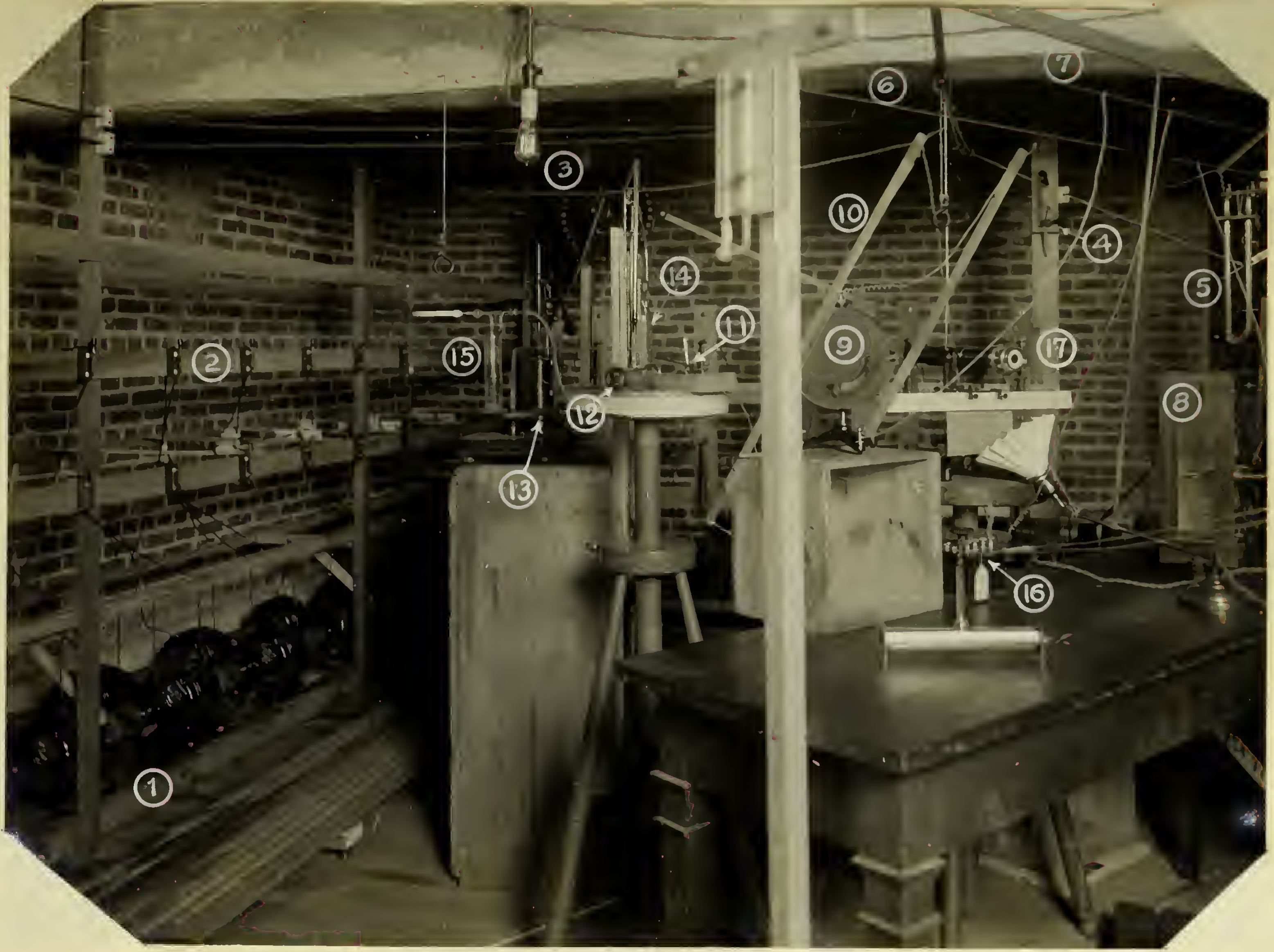


FIG. 1.

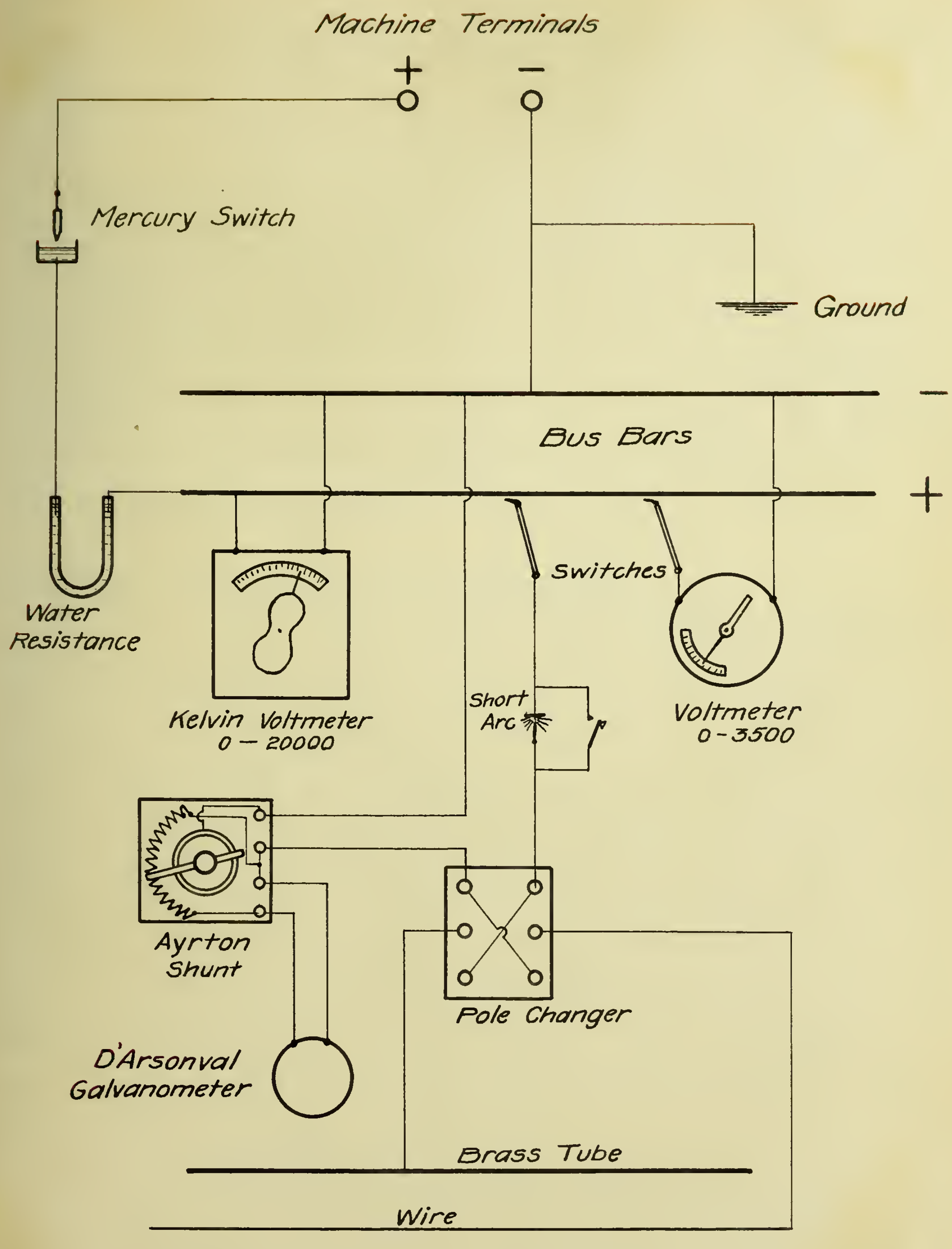


DIAGRAM OF CONNECTIONS

FIG. 2.

16) Ayrton Shunt for Galvanometer.

17) Telescope for reading Deflection of Galvanometer.

The diagram of connections in Fig.2 is self-explanatory. It might be remarked that the apparatus labeled "Short Arc" consists of an air-gap between the head of a tack and a copper wire. This spark-gap could be cut out of the circuit by closing a shunt around it. Special care was taken in setting up the apparatus to thoroughly insulate it from the ground, except that the negative terminal of the generating apparatus was grounded, in order to minimize the danger from shock.

Section 2: Instruments and Calibrations.

The voltage between the bus-bars and hence, with sufficient accuracy, the difference of potential impressed upon the corona apparatus, was measured by means of electrostatic voltmeters. For the lower ranges an instrument made by Max Kohl was employed. It had a range of 3500 volts and was accurate to within 1%. This conclusion was reached by comparing its indications with those obtained by adding the voltages of the machines used as given by a 750 volt Weston direct-current portable voltmeter which had been carefully calibrated by a potentiometer. This electrostatic voltmeter could be disconnected from the positive bus-bar when the voltage increased above its range.

For the measurements of the higher differences of potential a vertical type Kelvin electrostatic voltmeter made by James White of Glasgow was used. This instrument had three ranges of 5000, 10000, and 20000 volts which could be secured by hanging the proper weights from a lug at the bottom of the needle. Only

the 10000 and 20000 ranges were used. The lower part of the 10000 range was calibrated by the same method as for the Kohl voltmeter as well as by measuring the voltages indicated by the Weston voltmeter when a high resistance was inserted in series with it. This high resistance was made of a U-tube containing alcohol into which two platinum wires dipped. This resistance was kept from heating by immersing it in a mixture of ice and water. Under these conditions the resistance was very constant for the small currents used. Following is a table of the corrections employed:

Reading	Corrections to be Subtracted
3600	165
3800	150
4000	135
4200	140
4400	155
4600	140
4800	125
5000	80
5600	75
6000	50
7000	0

The higher ranges of this voltmeter were calibrated by reference to an attracted disk electrometer. This instrument had a disk 5.5 cm. in diameter. The aperture of the guard-ring was 5.9 cm. in diameter and the outside diameter of the guard ring was 16.0 cm. A separation of 1.5 cm. was used between the disk and the lower plate.

Due to the non-uniformity of the field at the edge of the disk, an edge correction must be applied to the indications of the electrometer. This edge correction is treated by Maxwell in Vol.1. of his"Electricity and Magnetism" and the conclusions reached are briefly as follows:-

Let

R = radius of disk
R'= radius of aperture.
D = distance between plates.
A = effective area of disk.
$\alpha = 0.22063\ (R'- R)$.
W = wt. in grams to balance.

Then

$$V = \sqrt{\frac{8\pi g W}{A}} \times D$$

where

$$A = \frac{1}{2}\pi \left(R^2 + R'^2 - (R'^2 - R^2)\frac{\alpha}{D+\alpha}\right)$$

Using the numerical constants of the instrument as given above, there results:

$$\alpha = 0.044$$

$$A = 25.474 \text{ sq. cm.}$$

We may write $V = k\sqrt{W}$, where k is the constant $D\sqrt{\frac{8\pi g}{A}}$. Then k = 13992.3. By a similar series of operations we find that for plates 1 cm. apart, k = 9357.6.

By use of the value k = 14000, which is nearly enough correct, the values of W to balance for different voltages were calculated and a test run to determine how closely these values checked with the actual weights required for a balance when the voltages indicated by the electrostatic voltmeter were impressed. The results are given in the table below:

10000 Volt Range			20000 Volt Range		
Voltage Indicated	W Theoretical	W Actual	Voltage Indicated	W Theoretical	W Actual
5000	127.5 gr.	125 g.	10000	510 g.	510 g.
6000	183.7	184	11000	617	617
7000	250.0	250	12000	735	740
8000	327	327	13000	863	860
9000	413	420	14000	1000	1000
10000	510	520	15000	1147	1120

The balance used was a rather clumsy affair but the readings were performed with all possible care and the above results should be very nearly correct. A consideration of these

figures with due regard to the accuracy of the determinations led to the adoption of the following calibration:

Voltage Indicated	Actual Voltage
10000 v. range	
5000	4920
6000	5950
7000	7000
8000	8000
9000	9100
10000	10200
20000 v. range	
10000	10000
11000	11000
12000	12075
13000	12950
14000	14000
15000	14700

D'Arsonval galvanometers were used to measure the discharge currents obtained with the various pieces of corona apparatus. Most of the characteristic curves further on in this thesis were taken with a very sensitive Leeds and Northrup galvanometer which had a small coil, a resistance with connecting wires of 326.0 ohms, and was practically dead-beat. It was really too sensitive and needed constant care to see that its figure of merit had not altered. For the later moisture and pressure determinations which extended over some days, a less sensitive instrument made by Nalder Bros. & Co., was used. This had a heavier coil, a resistance with connecting wires of 849.5 ohms and a period of six seconds. Its

figure of merit was about five times that of the first instrument.

The figure of merit of these galvanometers was determined from time to time, using accurate resistances of high value and as a source of e.m.f. either a dry cell or a standard cell. In the case of the dry cell, its e.m.f. was determined from the indications of an accurate Weston Laboratory Standard voltmeter.

An Ayrton universal shunt was used in connection with the galvanometer. This shunt box had five coils connected between contact points as follows:

Connection of Coil	Resistance of Coil
Pt. 0 to Pt. 0.0001	0.3 ohms
".0001" " .001	2.7 "
" .001" " .01	27 "
" .01" " .1	270 "
" .1" " 1	2700 "
Total Resistance----------	3000 "

A movable contact arm served to connect in series with the galvanomater all the resistance lying between point 1 and the point with which the arm made contact. The rest of the resistance was then in series with the corona apparatus. By taking into account the resistance of the galvanometer, the proper shunt factor by which to multiply the current thru the galvanometer was easily calculated.

--Chapter III--

Preliminary Experiments

When this thesis was undertaken, it was not apparent from the limited literature on the subject of the corona produced by continuous potentials what one might expect in the way of coronal phenomena which might be produced by potentials up to the total voltage of the generating sets, namely 15,000 volts. No glow could be obtained between flat plates; only an arc. Then an investigation was begun to find out what kind of terminals would have corona produced between them by the comparatively low voltage available.

A brass rod 0.637 mm. in diameter was located axially along a tube 4.45 cm. in diameter and the full voltage of the sets was impressed. No effect was visible. Then provision was made for exhausting the tube, and at about one-quarter atmosphere a discharge took place. This took the form of brilliant radial purple arcs terminating in bright blue "stars" on the walls of the tube. These arcs were in constant motion around the wire and along the tube and reminded one of a pinwheel. A fairly large sized wire was substituted for the rod and still no corona could be obtained at atmospheric pressure.

Fearing that no coronal effect could be produced by the generating sets, recourse was had to large influence machines. It was known that the silent discharge between points was of the same nature as the corona between wires and it was reasoned that if the e.m.f. of an influence machine were impressed between small parallel wires, a discharge would take place between them. Two bare #40 wires were stretched parallel to one another and a few centimeters apart and a silent discharge was found to take place between them. The appearance of the discharge was at once seen to depend upon the polarity. The discharge was discontinuous, small brushes on the negative wire corresponding to sections of uniform glow on the positive wire. The brushes were in a more or less constant movement back and forth along a short path, but they appeared to be more or less evenly spaced along the wire. It was also noticed that the wires vibrated and that the negative wire bowed in toward the positive which bowed away from the negative. It was as though a wind were blowing across the wires.

Another experiment was tried with a #40 wire above a sheet of tinfoil. With this arrangement and wire positive, a continuous glow appeared along the wire, while when the wire was negative the discontinuous brush discharge appeared again. Vibrations were also noticed with this apparatus.

A steel mandolin "E" string, 0.24 mm. in diameter was strung along the axis of a brass tube of about 3 cm. diameter and the wire and tube were connected to opposite polarities of the influence machine. If the wire was positive, a continuous bluish glow of markedly uniform appearance appeared along the wire. When the wire was negative, the discharge was in constant movement and

seemed to consist of countless purple streamers or brushes. There seemed to be no appearance of regularity of spacing of isolated brushes.

When these tests were run it was noticed that the main discharge knobs on the machine could be moved together until they almost touched before a spark would pass. This indicated that the difference of potential between the parallel wires, for example, could not be very high, not over 10,000 volts perhaps. This fact suggested that similar discharges with small wires should be produced by the continuous potentials from the generating sets. So the experiments were carried out again and it was found that the same effects were produced by the generators.

The crude tube apparatus was fastened to a board by means of nails driven into the wood and bearing against the wall of the tube. Connection was made to the tube by wrapping a wire around one of these wires. This wire became loose and separated .01 inch or so from the tube. The consequence was that a short arc was established between the nail and the tube. The presence of the arc caused a marked difference in the character of the positive discharge. With a potential difference of about 8000 volts and the wire positive to the tube, a very active discharge took place between the wire and tube. The whole tube appeared filled with a bluish glow particularly brilliant around the wire, where an uneven effect was apparent, resembling a brush discharge. The discharge was unstable and variations in the arc produced marked variations in the discharge. After the bluish glow had continued for some minutes, the nature of the discharge became suddenly different. Purple arcs appeared, of much the same nature as those mentioned above in connection with the discharge from a rod at low pressure.

After a while the discharge would resume its former character and then the process would repeat. The arc between the nail and tube appeared bluer while the whirl-i-gig discharge was going on. A small wire was slipped in to bridge the gap between nail and tube and then the discharge became merely a faint blue glow of a uniform nature, apparent only in the immediate vicinity of the wire. With the gap closed and the wire negative, an entirely different discharge took place. Small purple brush-like discharges were clustered irregularly along and around the wire and these held their positions fairly constant. When the arc was again introduced, the discharge appeared somewhat dimmer, although keeping its nature about the same, as far as could be seen by looking from the end of the tube.

PART II

EXPERIMENTAL INVESTIGATION

--Chapter IV--

Characteristic Curves at Atmospheric Pressure

Section 1: Preliminary Remarks.

As has already been noted in Chap.I., the use of cylindrical fields in an investigation of the corona is advantageous both from standpoint of ease of control of such factors as humidity and pressure and from the fact that the voltage needed to produce corona is much smaller than is the case with wires in the open air.

In order to study the influence of diameter of wire upon critical voltage and discharge current, a number of different sizes of bare wire ranging from #40 to #10 copper were obtained from the manufacturers and an apparatus was constructed in which the tests could be carried out. This apparatus is shown in Fig.3.and consists essentially of a brass tube 4.45 cm.in internal diameter, well insulated from its support and provided with means for accurately and tightly stretching a wire along its axis. The tube was provided with a small branch tube thru which the air

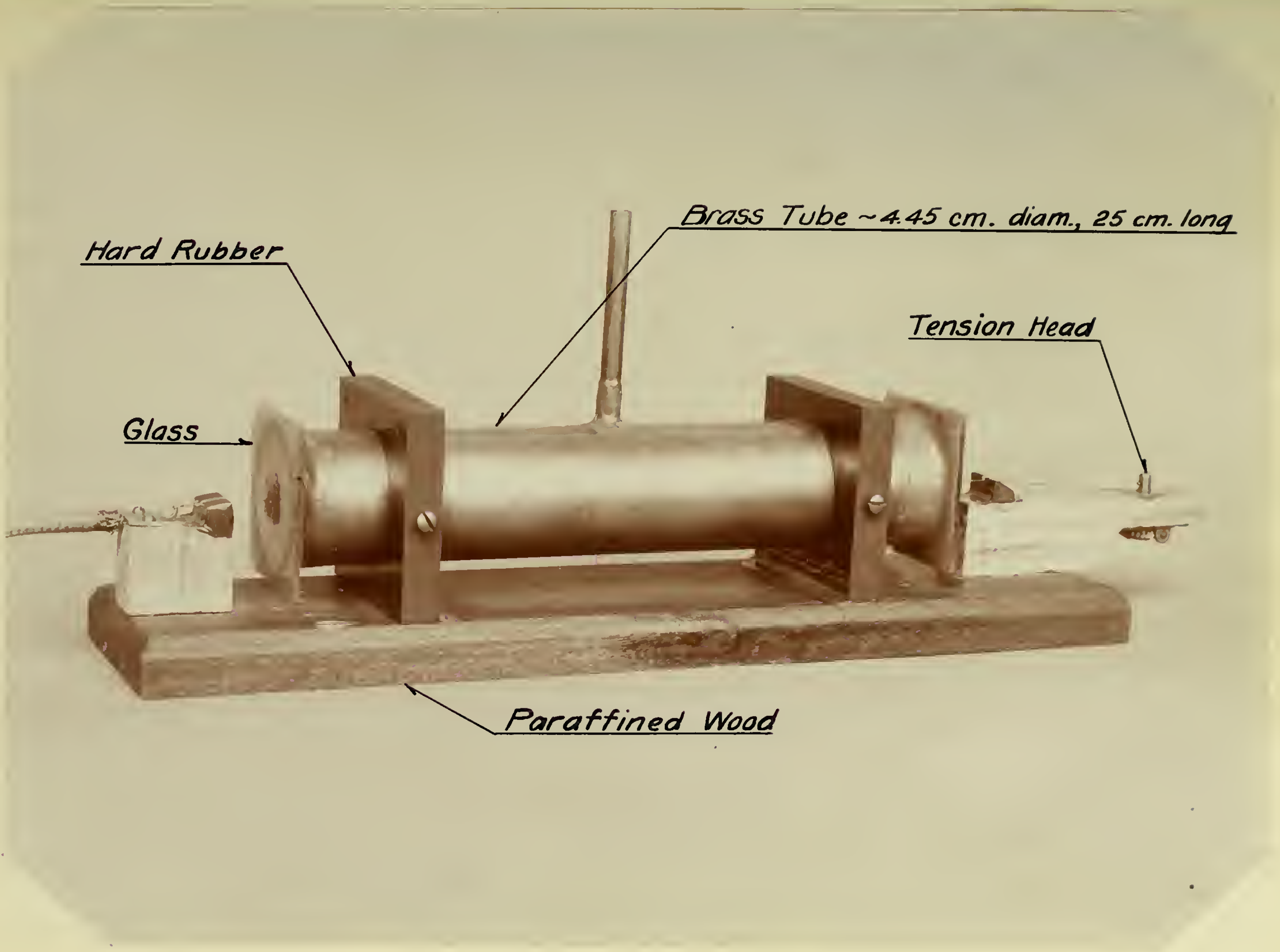

Brass Tube ~4.45 cm. diam., 25 cm. long
Hard Rubber
Tension Head
Glass
Paraffined Wood

FIG. 3.

could be exhausted. The centering of the wire was accomplished by passing it over hard-rubber bridges in which there were notches axially located with respect to the tube and stretching it tightly by means of a mandolin tension-head. In order to limit definitely the length of the wire from which a discharge could take place, glass plates were sealed to the ends of the tube and the wire passed through holes in them about 3 mm. in diameter. For most of the characteristic voltage current curves, the exhaust tube and the holes in the plates were left open and the air in the tube had the same constitution as that in the room, at least at the beginning of the test.

In order to make sure that no current would flow thru the apparatus except that through the air, a small wire was arranged so that the tube was in the same condition as for a test except that none of the wire extended inside of the cylinder. Then differences of potential were applied up to 10000 volts and the currents measured. It was found that even at the highest voltage the current was insignificant.

Section 2: Method of Conducting Tests.

The tube was placed upon a laboratory stand whose top was covered by a layer of paraffine to improve the insulation from the ground. Wires were run from the pole-changing switch to the tube and wire, the motors started, the mercury contact switch closed, and all was ready for a test. For the first wires tested a start was made at a low voltage and the currents taken by small increments on the way up. It was soon found that the current flowing was negligible until the voltage approached that necessary for a visible glow and therefore later tests were started at a

voltage somewhere near the critical voltage. For each voltage the deflection of the galvanometer was read for both polarities of the wire.

When the wire was positive and the voltage neared that necessary to cause a visible glow, a very marked jump of the deflection would occur and a further increase of the voltage caused the current to increase very rapidly. The voltage at which this sudden increase of the deflection took place was called the "critical voltage". "Visible glow" was taken to mean the first appearance of light in the case of the wire positive. This glow appeared suddenly for all but the smallest wires, in which case the dimness of the glow made it hard to tell just where the limit of visibility was.

As has been noted in Chap.1. the presence of dirt or dust particles on the wire when negative has a marked effect upon the discharge. Often a spot or two on the wire would glow long before the wire as a whole was luminous. Due to this fact there is no definite critical voltage as in the case of the positive polarity, for the initial jump of the deflection is much a matter of chance. But as the voltage is increased, there occurs a critical voltage at which a flickering glow can be seen along the wire preliminary to the spreading of the discharge from a few spots over the whole wire. This phenomenon occurs at a definite voltage for a given size wire and it is this voltage which is givin the tables under "visible glow" for the negative polarity.

Readings of wet and dry bulb thermometers and an aneroid barometer were taken for each test and the per cent relative humidity was calculated. The barometer was checked from

time to time by reference to a very accurate mercurial barometer.

The silver wire used in these tests was really silver wire with a platinum core, known as "Wollaston" wire. This wire was used both in its original state, diameter 0.0517 mm. and with some of the silver dissolved off, giving wires of average diameter 0.027 and 0.037 mm.

The tungsten wire was of the sort used in 25 watt lamps.

The diameters of the very small wires were obtained by the use of a microscope fitted with a stage ruled with parallel lines.

Section 3: Variation of Critical Voltage and Glow Voltage.

Tables 1 to 13 give data on critical voltages and the voltages required to produce continuous visible glow for wires of diameters ranging from 0.027 mm. up to 1.28 mm. A study of these data showed the following facts:

a) For the smaller sizes, the critical voltage is considerably lower than the glow voltage, showing quite a current exists before a luminous discharge occurs. This applies for wire positive.

b) The smallest size for which there is no current for wire positive before glow appears is #36, diameter 0.135 mm.

c) For sizes larger than #36, current and glow appear simultaneously, for wire positive.

d) For wires from about #26 up for the negative polarity the current and the visible glow appear simultaneously, as a general rule.

Fig.13. gives curves showing the variation of the glow voltages with the radius of the wire. From these curves the following conclusions can be drawn:

e) For the smaller sizes, the negative glow appears before the positive.

f) For the larger sizes the positive glow appears before the negative.

g) The diameter 0.075 mm. is the boundary between these two regions.

Schaffers has noted this crossing of the curves for the starting points of the positive and negative coronae and he set 0.01 cm. radius as the boundary value between the two regions. He did not specify what he considered as the starting point of the negative corona and therefore it is not practicable to compare his value with that given above.

Section 4: Variation in the Nature of Corona.

During the tests for the characteristic curves a close watch was kept over the appearance of the corona and there is given below some of the characteristic changes and phenomena which were noted.

For the entire range of diameters there was very little change in the appearance of the positive corona, except for an increase in brightness with the voltage. It always presented a quiet, uniform, continuous, bluish glow. For high voltages the opening and closing of the circuit was attended by a flash of bluish light in the tube and if care was not taken to perform these operations quickly, there was likelihood of an arc starting between the wire and the tube, with the result that the wire, if it was small, was burned in two.

There was considerable change, however, in the appearance of the negative corona with increase of diameter and voltage. The negative corona on small wires starts with a bright spot or two, followed by a mixture of bright spots and brushes as the voltage is increased. With still increasing voltage there is more

of a continuous brush-like effect and the discharge becomes quite purple. For the highest voltages the corona is brilliant, purple, continuous, and in constant movement. For the smallest sizes, the negative corona is likely to take the form of a discharge consisting of isolated, more or less evenly spaced brushes. Marked regularity of spacing has often been observed. The discharge is noiseless for wires up to #26 (0.24 mm.) for which diameter a slight hissing appears. As the diameter increases, the hissing grows louder and the diameter of the corona increases.

In the case of the larger size wires, it is the general rule for the continuous negative brush discharge to appear immediately when the critical voltage is reached.

No flash at make or break of the circuit was observed when the wire was negative.

Section 5: Discussion of the Characteristic Curves.

A critical comparison of the characteristic curves in Figs.4 to 12 brings out the following points:

a) For a given voltage, the current increases with decrease of diameter of the wire.

b) For wires smaller in diameter than #40 (0.077 mm.) the current for negative polarity of the wire is always greater than for positive polarity.

c) In the case of #40 wire the currents for opposite polarities coincide very accurately for a small rise in voltage above the critical value, and then the negative current becomes and remains the larger.

d) For sizes greater than #40, the curves for the two polarities cross. For the lower voltages the positive current is the greater and vice versa for the higher voltages.

e) The characteristic curves become more nearly parallel to the current axis as the diameters increase.

TABLE 1

Silver Wire - Diameter 0.027 mm.

Temperature	26.6°C
Relative Humidity	54.4%
Barometric Pressure	741.55

	+	-
Critical Voltage	2100	1880
Visible Glow	2720	2520

PD	Galv. defl. in mm.		Shunt Factor		Current in 10^{-4} amp.	
	+	-	+	-	+	-
1750	1.1	1.2	1.0	1.0	0.000032	0.000035
2100	25.0	60.0	1.0	1.0	0.00072	0.00173
2500	66.7	50.7	1.0	11.09	0.00192	0.0162
2800	137.0	101.0	1.0	11.09	0.00394	0.0322
3000	18.2	147.0	11.09	11.09	0.0058	0.0469
3200	33.0	21.1	11.09	110.9	0.0105	0.0674
3500	101.0	36.7	11.09	110.9	0.0322	0.117
3860	30.9	69.0	110.9	110.9	0.0986	0.220
4350	66.2	122.8	110.9	110.9	0.212	0.392
4920	114.8	18.4	110.9	1109	0.335	0.588
5950	23.9	35.2	1109	1109	0.763	1.12
7000	39.4	56.7	1109	1109	1.26	1.81
8000	60.7	87.5	1109	1109	1.94	2.80
9100	82.0	113.0	1109	1109	2.62	3.61

wire broke 1/27/14

Wire rough: 0.027 is average of many readings.

Figure of merit of galvanometer 2.88×10^{-9} amp. per mm.

TABLE 2.

Silver Wire - Diameter 0.037 mm.

Temperature 26.7°C.
Relative Humidity 45.3%
Barometric Pressure 736.48 mm.

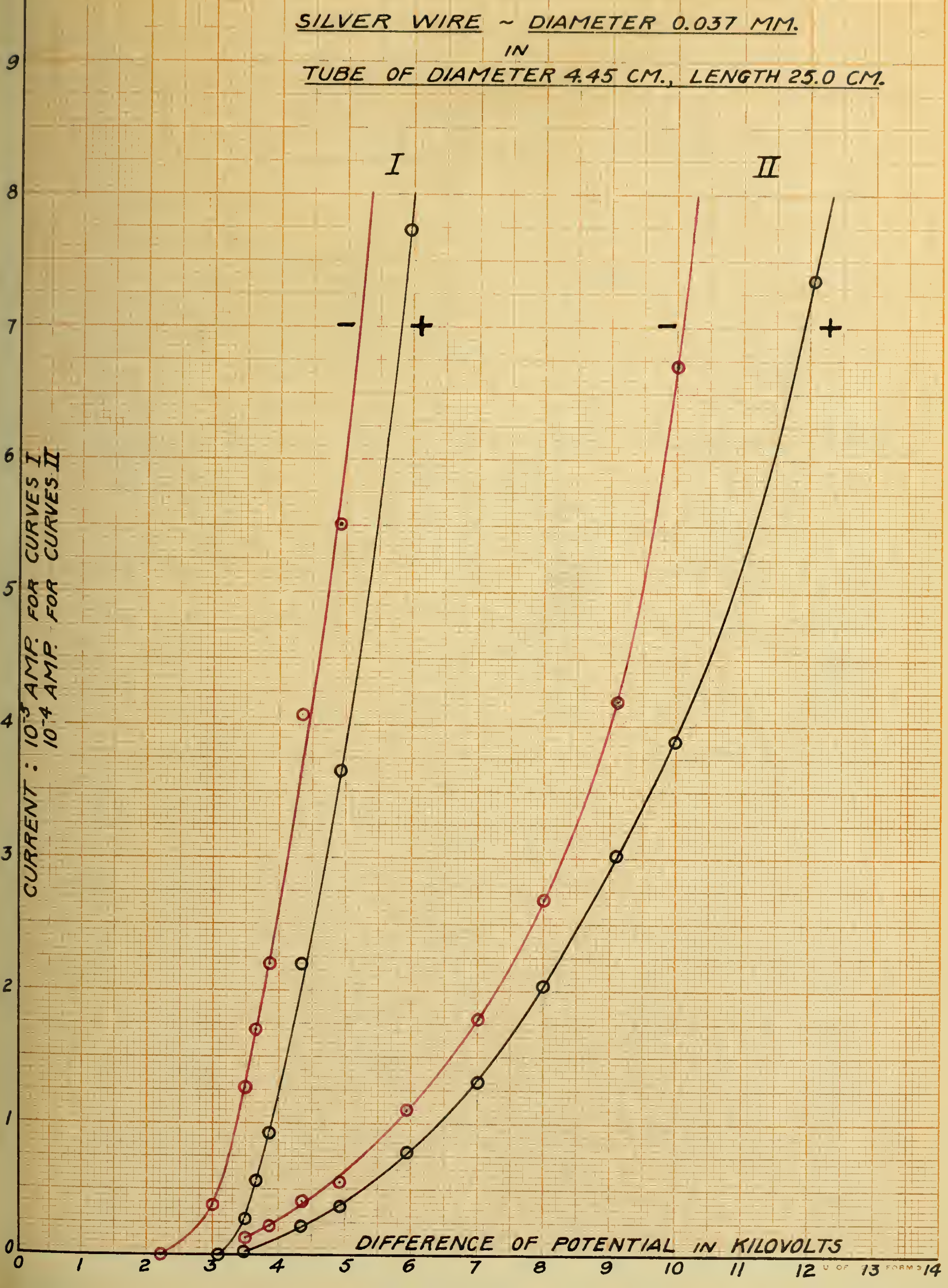
	+	-
Critical Voltage	3100	2200
Visible Glow	3380	3230

PD	Galv. defl. in mm.		Shunt Factor		Current in 10^{-4} amp.	
	+	-	+	-	+	-
2150	1.5	2.1	1.0	1.00	0.00004	0.00006
3000	4.0	117.0	1.0	11.09	0.00011	0.0374
3500	85.7	39.3	11.09	110.9	0.0274	0.126
3650	117.7	53.3	11.09	110.9	0.0565	0.170
3860	29.0	68.8	110.9	110.9	0.0926	0.220
4350	68.8	127.7	110.9	110.9	0.220	0.407
4920	114.3	172.7	110.9	110.9	0.365	0.551
5950	242.0	34.4	110.9	1109	0.773	1.10
7000	41.0	56.0	1109	1109	1.31	1.79
8000	64.0	84.0	1109	1109	2.04	2.68
9100	94.7	131.0	1109	1109	3.02	4.18
10000	121.7	21.0	1109	11090	3.88	6.7
12075	23.0	58.7	11090	11090	7.35	18.8
14000	---	wire broke - arc.		---	---	---

Figure of merit of galvanometer 2.88 x 10^{-9} amp. per mm. defl.

1/24/14

FIG. 4.


SILVER WIRE ~ DIAMETER 0.037 MM.
IN
TUBE OF DIAMETER 4.45 CM., LENGTH 25.0 CM.
I
II
−
+
−
+
CURRENT: 10^{-3} AMP. FOR CURVES I
10^{-4} AMP. FOR CURVES II
DIFFERENCE OF POTENTIAL IN KILOVOLTS
0
1
2
3
4
5
6
7
8
9
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
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FORM 3

TABLE 3.

Tungsten Wire - Diameter 0.046 mm.

Temperature	25.3°C.
Relative Humidity	40.5%
Barometric Pressure	740.25 mm.

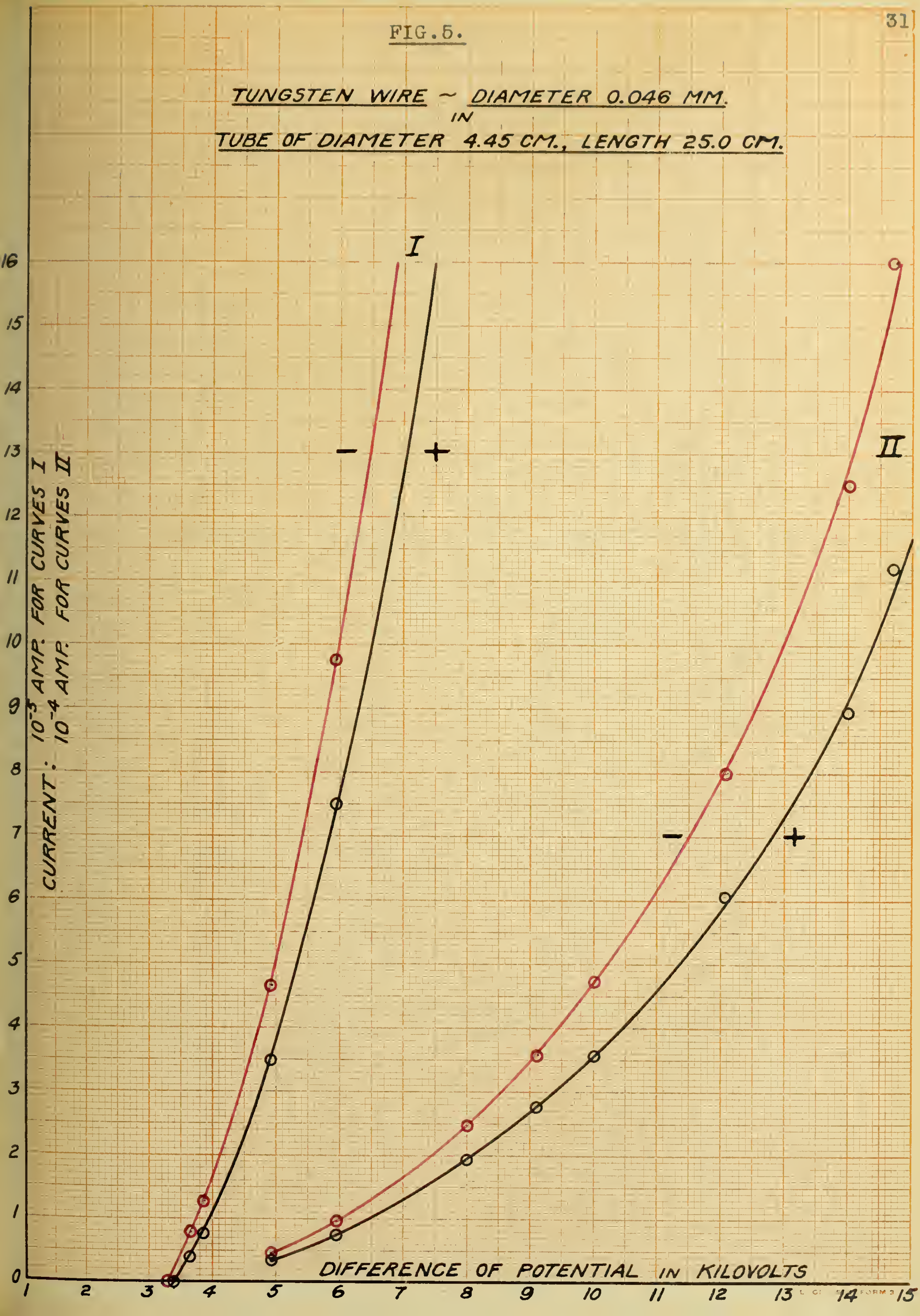
	+	-
Critical Voltage	3380	2800
Visible Glow	3500	3300

PD	Galv. defl. in mm.		Shunt Factor		Current in 10^{-4} amp.	
	+	-	+	-	+	-
2500	1.3	2.0	1.0	1.0	00.000037	00.000057
3000	2.0	10.0	1.0	1.0	00.000057	00.00029
3500	24.7	84.3	11.09	11.09	00.00788	00.0269
3650	131.7	24.8	11.09	110.9	00.0420	00.0791
3860	24.2	39.5	110.9	110.9	00.0773	00.126
4920	109.0	145.7	110.9	110.9	00.348	00.465
5950	23.5	30.5	1109	1109	00.750	00.974
8000	60.3	77.7	1109	1109	01.93	02.48
9100	86.2	111.7	1109	1109	02.75	03.56
10000	111.7	147.7	1109	1109	03.56	04.71
12075	19.0	25.0	11090	11090	06.06	07.98
14000	28.0	39.0	11090	11090	08.94	12.5
14700	35.0	50.0	11090	11090	11.2	16.0

Figure of merit of galvanometer 2.88 x 10^{-9} amp. per mm.

1/22/14

FIG. 5.



TUNGSTEN WIRE ~ DIAMETER 0.046 MM.
IN
TUBE OF DIAMETER 4.45 CM., LENGTH 25.0 CM.

TABLE 4.

Silver Wire - Diameter 0.0517 mm.

Ascending and Descending Series

Temperature	25.0°C.
Relative Humidity	54.2%
Barometric Pressure	747.0

	+		-	
	Start	Finish	Start	Finish
Critical Voltage	3500	3550	3300	3300
Visible Glow	3630	3650	3500	3525

P.D.	+ Current in 10^{-4} amp.		- Current in 10^{-4} amp.	
	Up	Down	Up	Down
3860	0.0260	0.0241	0.0768	0.0735
4920	0.244	0.234	0.362	0.345
5950	0.619	0.566	0.820	0.794
7000	1.04	1.03	1.42	1.37
8000	1.63	1.63	2.15	2.15
9100	2.41	2.47	3.17	3.22
10000	3.19	3.25	4.17	4.23
11000	4.38	4.42	5.70	6.02
12075	5.86	5.86	8.04	8.04

During this test the air in the tube was not renewed, thus making the conditions the same as for the rest of the characteristic curves.

4/23/14

FIG.6.

SILVER WIRE ~ DIAMETER 0.0517 MM.
IN
TUBE OF DIAMETER 4.45 CM., LENGTH 25.0 CM.
ASCENDING AND DESCENDING SERIES

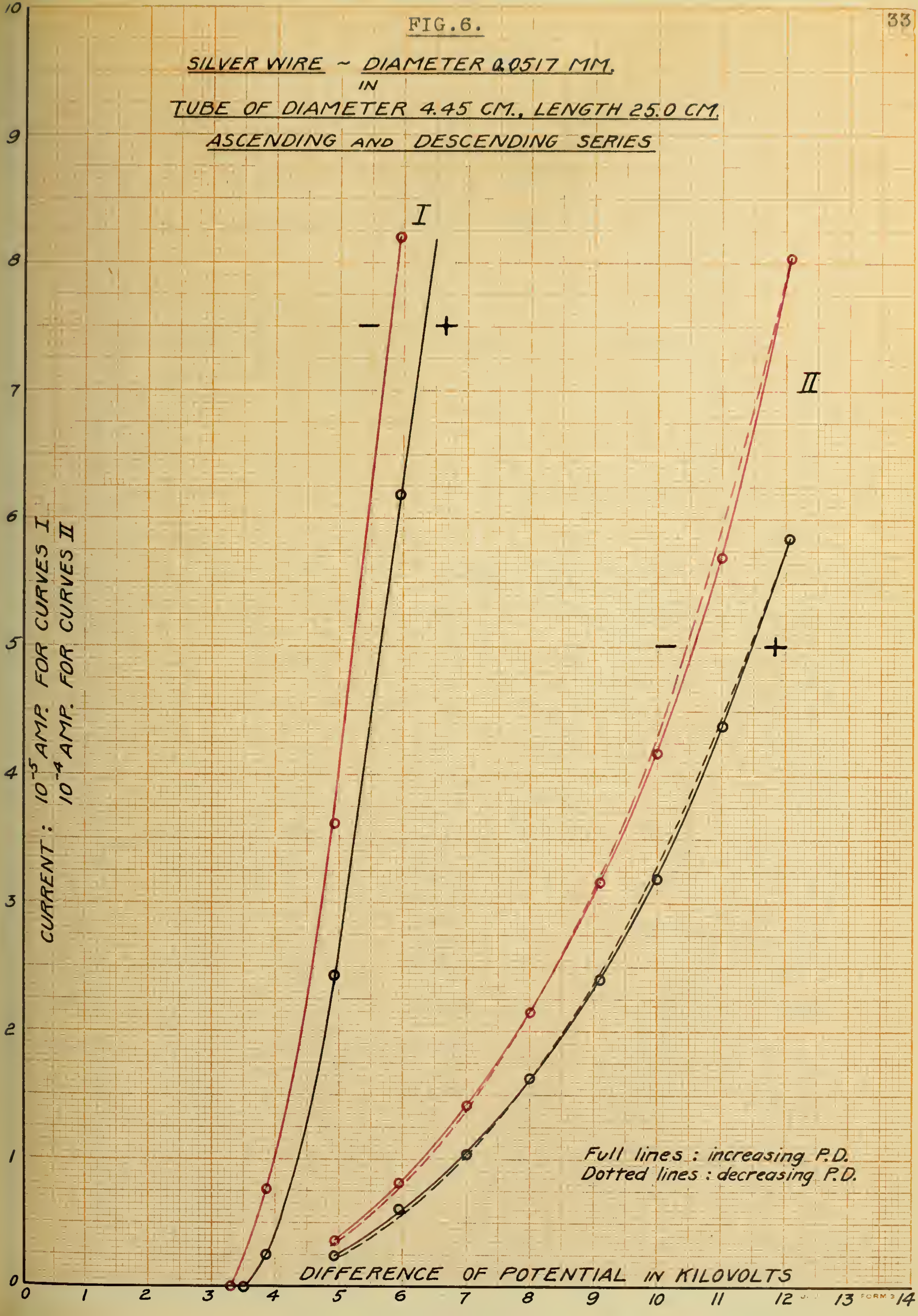


TABLE 5.

#40 B. & S. Copper Wire - Diameter 0.077 mm.

Temperature	25.0°C.
Relative Humidity	41.6%
Barometric Pressure	745.3 mm.

	+	-
Critical Voltage	3980	3860
Visible Glow	4060	4060

PD	Galv. defl. in mm.		Shunt Factor		Current in 10^{-4} amp.	
	+	-	+	-	+	-
3000	2.0	2.0	1.0	1.0	00.000058	00.000058
3860	3.0	7.0	1.0	1.0	00.000086	00.00020
4150	43.0	43.0	11.09	11.09	00.0137	00.0137
4350	149.0	149.0	11.09	11.09	00.0476	00.0476
4920	53.7	62.0	110.9	110.9	00.171	00.198
5950	167.7	195.0	110.9	110.9	00.535	00.622
7000	31.2	38.1	1109	1109	00.995	1.22
8000	53.0	61.2	1109	1109	1.69	1.95
9100	76.7	90.6	1109	1109	2.45	2.89
10000	104.8	125.3	1109	1109	3.35	4.00
12075	18.3	23.0	11090	11090	5.84	7.34
14000	29.3	37.9	11090	11090	9.35	12.1
14700	35.3	45.5	11090	11090	11.10	14.5

Figure of merit of galvanometer 2.88×10^{-9} amp. per mm.

1/21/14

FIG. 7.

*40 B. & S. COPPER WIRE ~ DIAMETER 0.077 MM.
IN
TUBE OF DIAMETER 4.45 CM., LENGTH 25.0 CM.

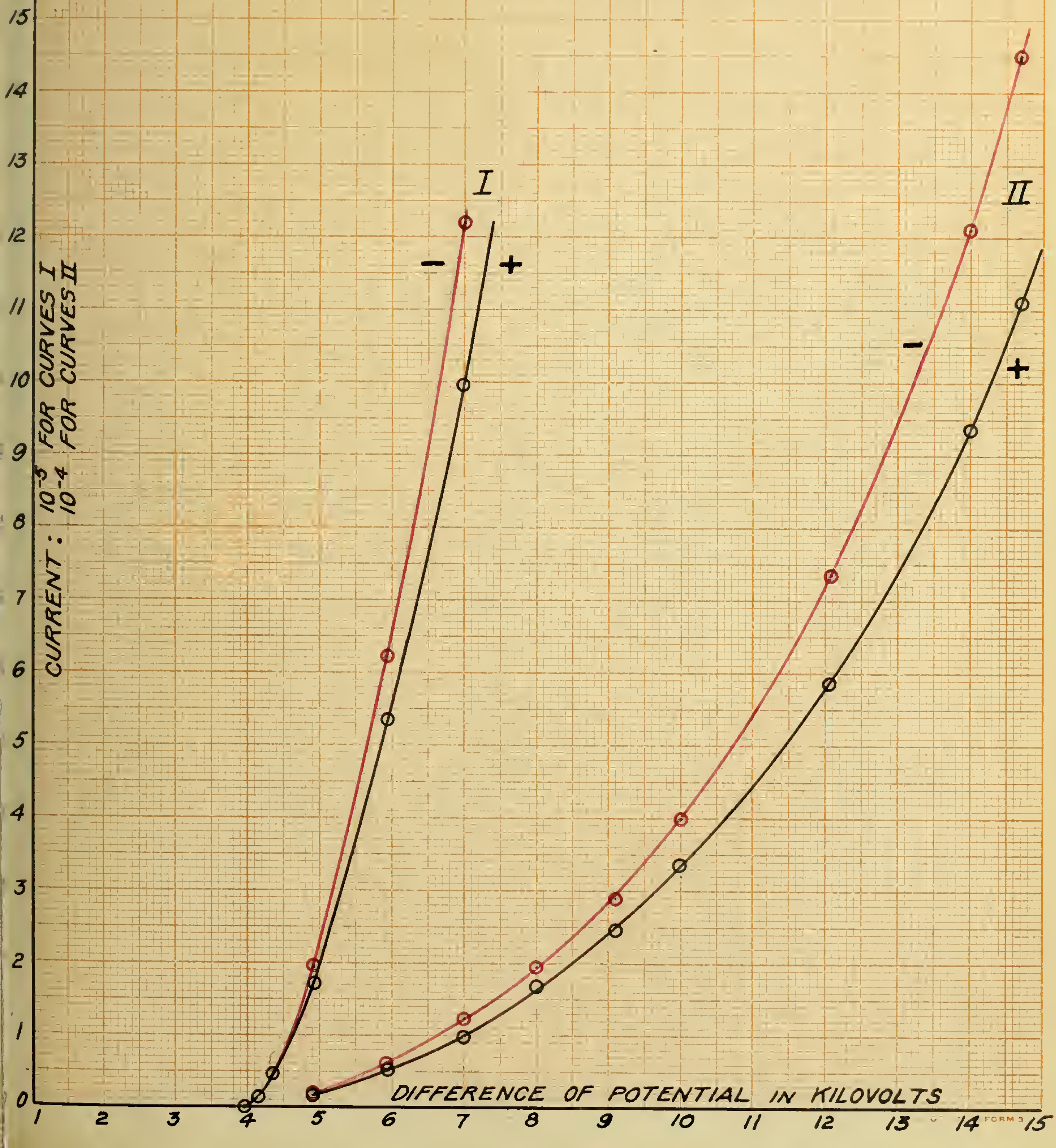


TABLE 6.

#40 B. & S. Copper Wire

Redetermination: Voltage Increased to 13000 and then Decreased

Temperature		25.0°C.
Relative Humidity	Start	60.6%
	Finish	55.7%
Barometric Pressure	Start	744.0 mm.
	Finish	742.3 mm.

	+		-	
	Start	Finish	Start	Finish
Critical Voltage	4060	4080	--	--
Visible Glow	4060	4100	4060	4060

D.P.	+ Current in 10^{-4} amp.		- Current in 10^{-4} amp.	
	Up	Down	Up	Down
4460	0.0602	0.0573	0.0780	0.0806
4920	0.150	0.143	0.195	0.189
5950	0.475	0.462	0.586	0.566
7000	0.897	0.878	1.10	1.075
8000	1.47	1.50	1.75	1.79
9100	2.29	2.31	2.67	2.73
10000	3.06	3.12	3.61	3.71
11000	4.29	4.29	4.95	5.03
12075	5.69	5.66	6.51	6.76
12950	7.22	7.22	8.45	8.45

4/24/14

TABLE 7.

#36 B. & S. Copper Wire - Diameter 0.135 mm.

Temperature 25.0°C.

Relative Humidity 45.0%

Barometric Pressure 733.85 mm.

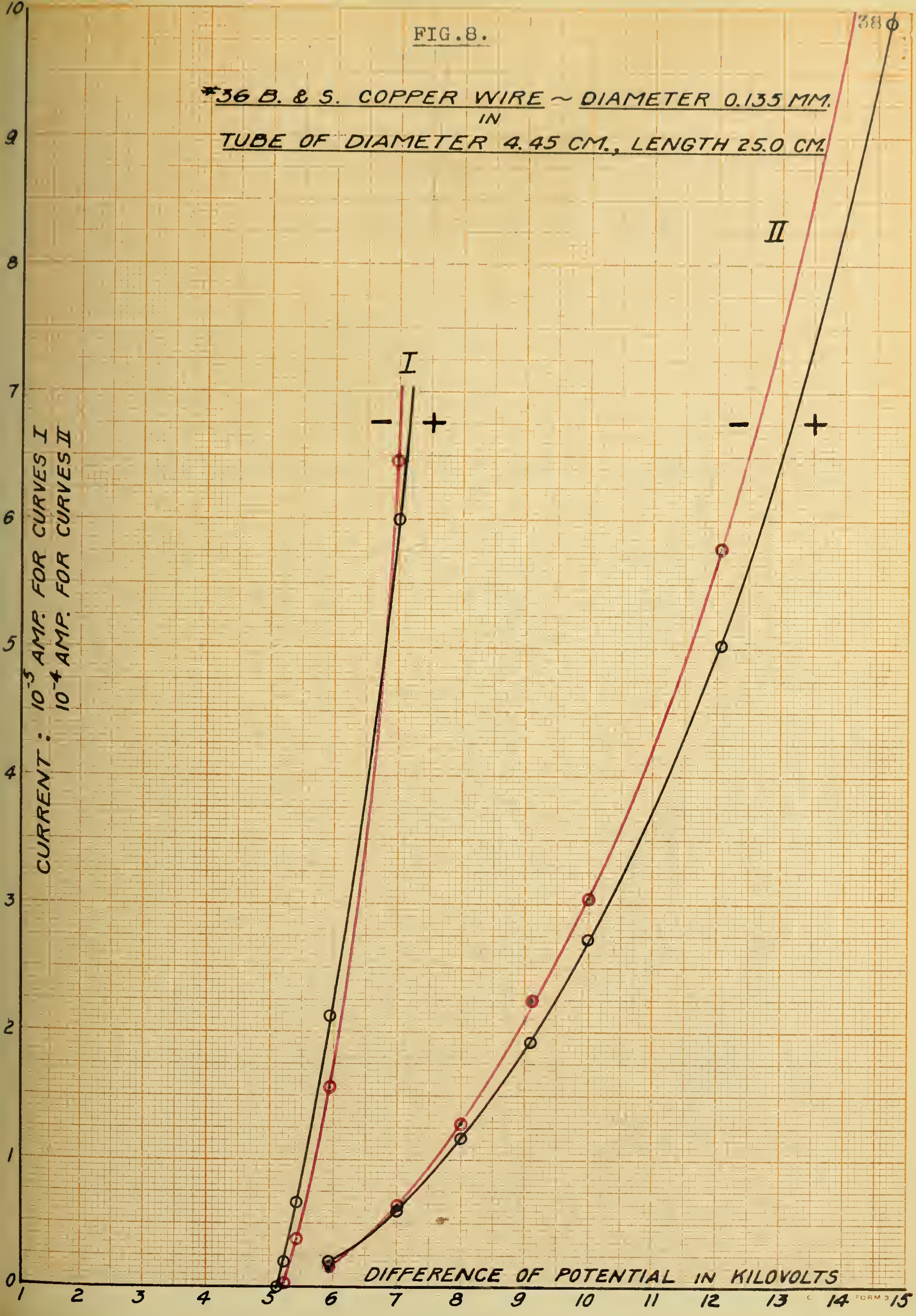
	+	-
Critical Voltage	5120	4350
Visible Glow	5140	5320

PD	Galv. defl. in mm.		Shunt Factor		Current in 10^{-4} amp.	
	+	-	+	-	+	-
3860	2.1	3.9	1.0	1.0	0.000060	00.000112
4350	2.3	9.7	1.0	1.0	0.000066	00.00028
4920	3.5	26.3	1.0	1.0	0.000101	00.00076
5220	65.0	190.0	11.09	1.0	0.0207	00.00547
5420	20.5	117.0	110.9	11.09	0.0655	00.0374
5950	66.4	49.0	110.9	110.9	0.212	00.156
7000	187.7	202.0	110.9	110.9	0.600	00.645
8000	36.7	40.1	1109	1109	1.17	1.28
9100	60.1	70.0	1109	1109	1.92	2.24
10000	85.5	95.2	1109	1109	2.73	3.04
12075	157.3	181.0	1109	1109	5.02	5.78
14700	31.0	35.0	11090	11090	9.90	11.2

Figure of merit of galvanometer 2.88 x 10^{-9} amp. per mm.

1/19/14

FIG.8.



*36 B. & S. COPPER WIRE ~ DIAMETER 0.135 MM.
IN
TUBE OF DIAMETER 4.45 CM., LENGTH 25.0 CM.

TABLE 8.

"E" Steel Mandolin String - Diameter 0.241 mm.

Temperature 24.8°C.

Relative Humidity 42.0%

Barometric Pressure 751.21 mm.

	+	-
Critical Voltage	6600	6760
Visible Glow	6600	6840

P.D.	Galv. defl. in mm.		Shunt Factor		Current in 10^{-4} amp.	
	+	-	+	-	+	-
5950	2.0	2.0	1.0	1.0	0.000058	0.000058
6500	2.5	3.9	1.0	1.0	0.000072	0.000112
6700	3.1	18.3	1.0	11.09	0.000089	0.00585
7000	19.9	67.0	110.9	11.09	0.0635	0.0214
7500	73.3	55.3	110.9	110.9	0.234	0.177
8000	147.4	130.4	110.9	110.9	0.471	0.417
9100	32.1	30.7	1109	1109	1.026	0.980
10000	52.5	51.4	1109	1109	1.68	1.64
12075	117.0	117.3	1109	1109	3.74	3.75
14000	19.7	21.6	11090	11090	6.29	6.90
14700	26.1	28.0	11090	11090	8.33	8.94

Figure of merit of galvanometer 2.88×10^{-9} amp. per mm.

1/13/14

FIG. 9.

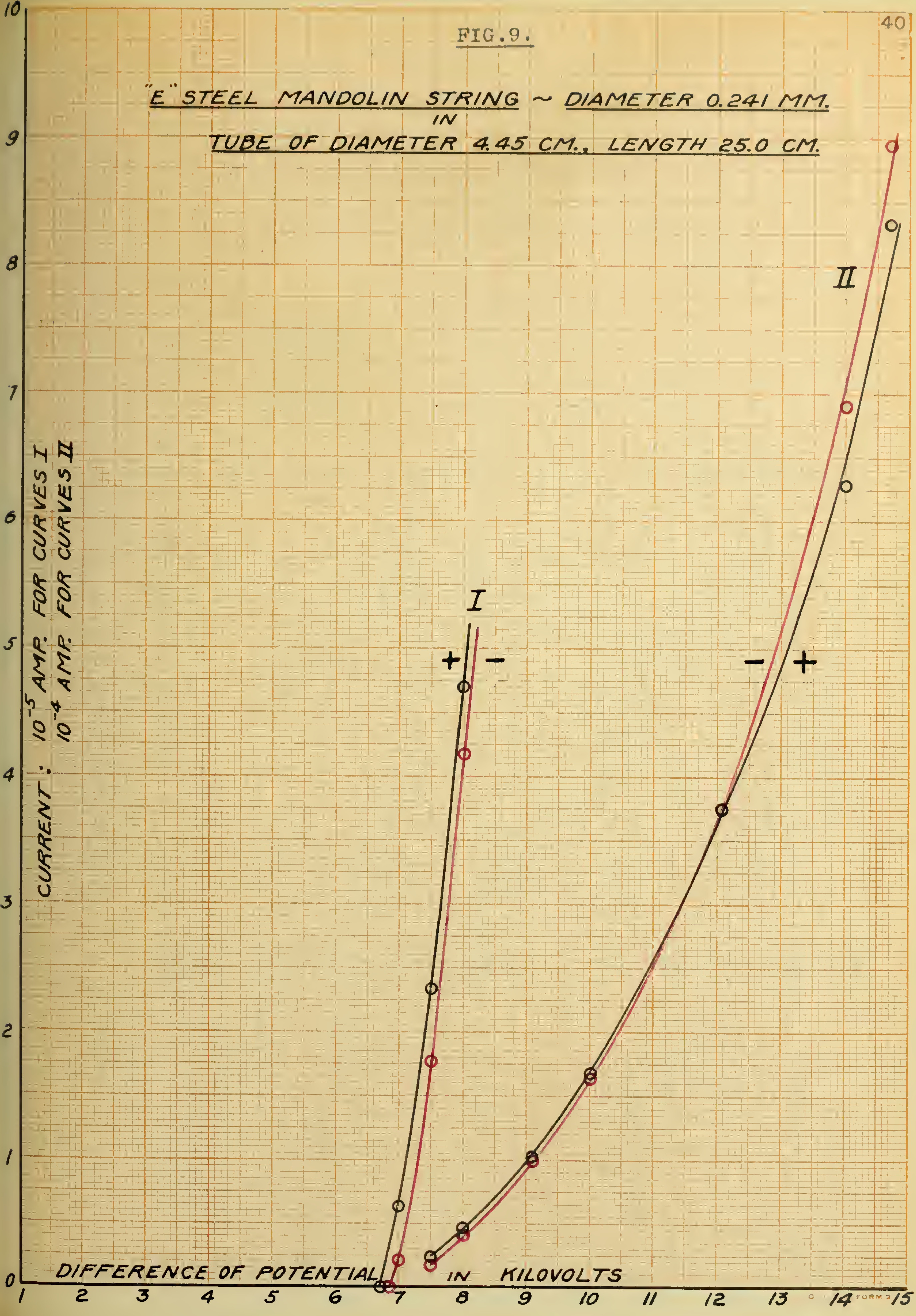

"E" STEEL MANDOLIN STRING ~ DIAMETER 0.241 MM.
IN
TUBE OF DIAMETER 4.45 CM., LENGTH 25.0 CM.
CURRENT: 10^{-5} AMP. FOR CURVES I
10^{-4} AMP. FOR CURVES II
DIFFERENCE OF POTENTIAL IN KILOVOLTS
I
+
−
II
−
+
0
1
2
3
4
5
6
7
8
9
10
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

TABLE 9.

#30 B. & S. Copper Wire 0.260 mm.

Temperature	23.6°C.
Relative Humidity	33.9%
Barometric Pressure	755.89 mm.

	+	-
Critical Voltage	7180	---
Visible Glow	7180	7660

P.D.	Galv. defl. in mm.		Shunt Factor		Current in 10^{-4} amp.	
	+	-	+	-	+	-
7500	38.5	45.0	110.9	1.0	0.123	0.0013
8000	110.0	44.0	110.9	110.9	0.351	0.140
9100	27.5	24.3	1109	1109	0.878	0.775
10000	44.5	45.5	1109	1109	1.42	1.45
11000	73.1	74.5	1109	1109	2.33	2.38
12075	107.2	112.1	1109	1109	3.42	3.58
12950	13.7	14.5	11090	11090	4.37	4.63
14000	18.4	18.7	11090	11090	5.87	5.97
14700	23.1	23.5	11090	11090	7.38	7.50

Figure of merit of galvanometer 2.88×10^{-9} amp. per mm.

2/11/14

FIG. 10.

*30 B. & S. COPPER WIRE ~ DIAMETER 0.26 MM.
IN
TUBE OF DIAMETER 4.45 CM., LENGTH 25.0 CM.

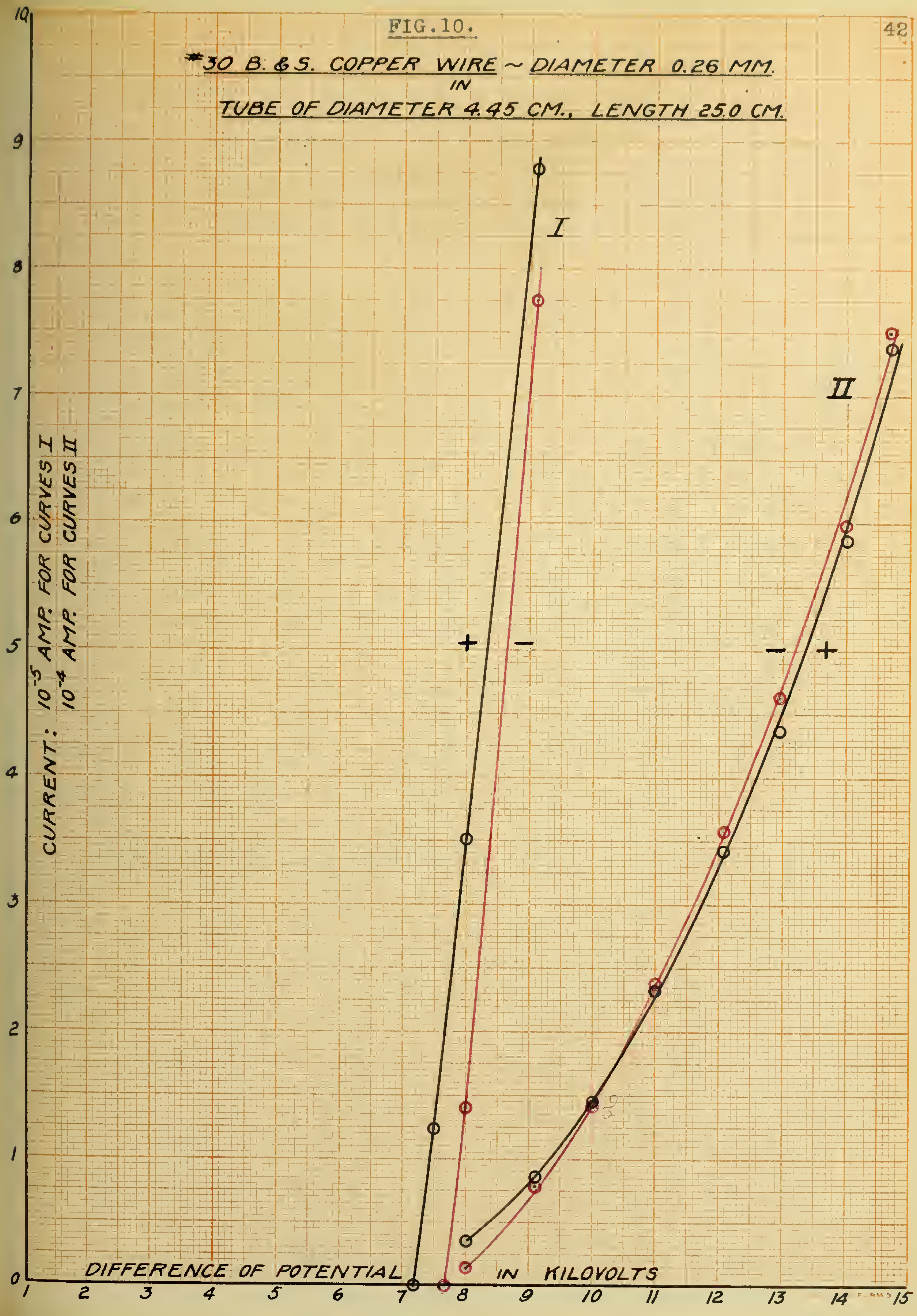


TABLE 10.

#26 B. & S. Copper Wire - Diameter 0.41 mm.

Temperature 26.0°C.
Relative Humidity 29.2%
Barometric Pressure 746.86 [illegible]

	+	-
Critical Voltage	8900	9370
Visible Glow	8900	9370

P.D.	Galv. defl. in mm.		Shunt Factor		Current in 10^{-4} amp.	
	+	-	+	-	+	-
9100	41.2	1.5	110.9	1.0	0.132	0.000043
10000	187.7	116.3	110.9	110.9	0.599	0.371
11000	41.0	39.3	1109.0	1109	1.31	1.26
12075	72.0	76.5	1109.0	1109	2.30	2.44
12950	104.9	112.0	1109.0	1109	3.35	3.58
14000	146.2	155.8	1109.0	1109	4.67	4.97
14700	197.0	202.0	1109.0	1109	6.29	6.45

Figure of merit of galvanometer 2.88 x 10^{-9} amp. per mm.

2/5/14

FIG. 11.

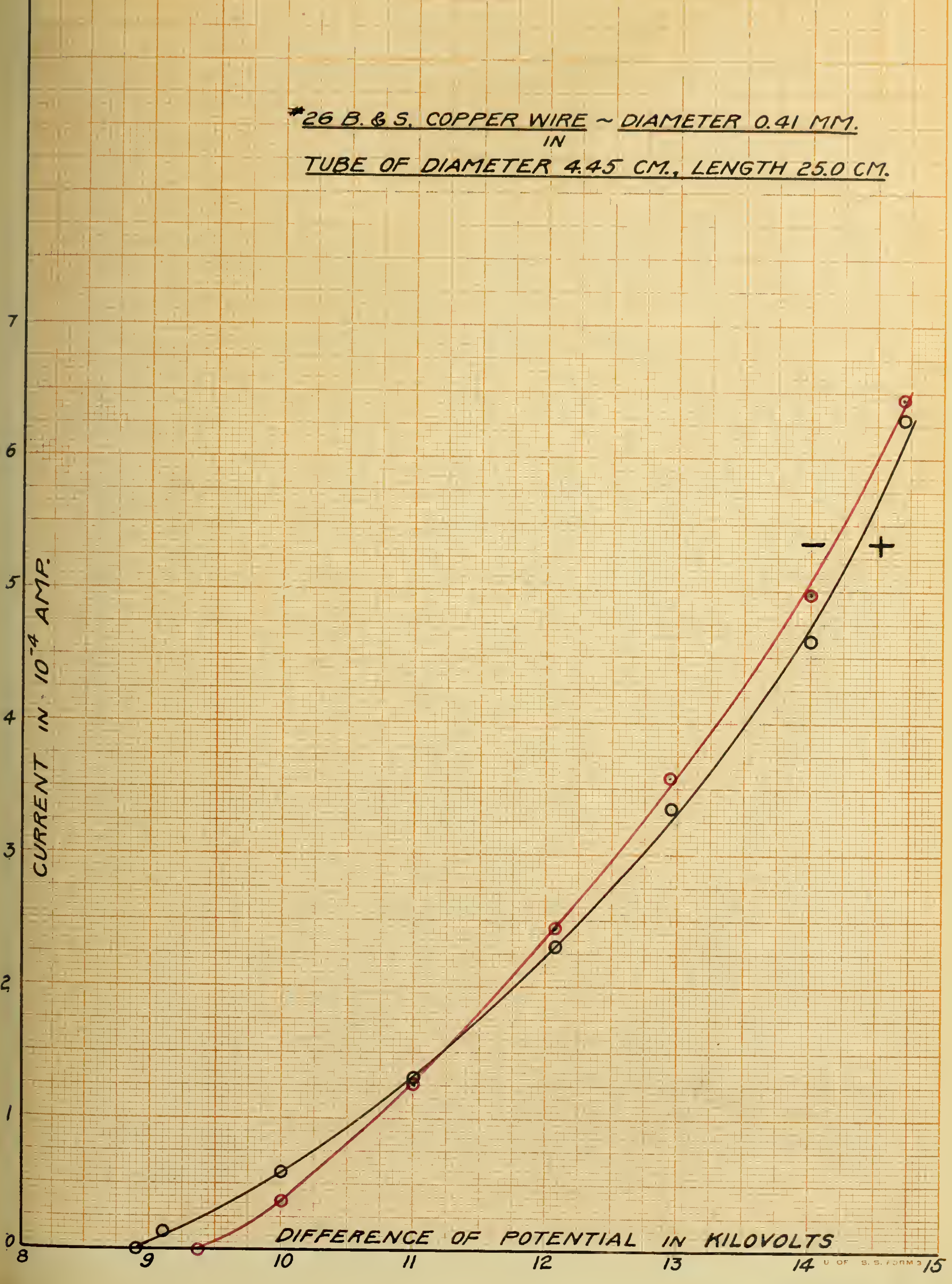

*26 B. & S. COPPER WIRE ~ DIAMETER 0.41 MM.
IN
TUBE OF DIAMETER 4.45 CM., LENGTH 25.0 CM.
CURRENT IN 10^{-4} AMP.
DIFFERENCE OF POTENTIAL IN KILOVOLTS
−
+
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

TABLE 11.

#22 B. & S. Copper Wire - Diameter 0.65 mm.

Temperature	26.1°
Relative Humidity	31.6%
Barometric Pressure	750.08 mm.

	+	-
Critical Voltage	9700	11440
Visible Gl Glow	10880	11440

P.D.	Galv. defl. in mm.		Shunt Factor		Current in 10^{-4} amp.	
	+	-	+	-	+	-
10000	30.0	37.0	1.0	11.09	0.000086	0.0118
11000	39.7	43.1	110.9	110.9	0.127	0.137
11400	125.5	64.7	110.9	110.9	0.400	0.207
12075	29.0	23.0	1109.0	1109.0	0.925	0.734
12950	56.4	61.0	1109.0	1109.0	1.80	1.95
14000	90.7	97.2	1109.0	1109.0	2.90	3.10
14700	140.0	145.7	1109.0	1109.0	4.47	4.65

Figure of merit of galvanometer 2.88 x 10^{-9} amp. per mm.

Wire (-) one bright spot at 9100.

A diffuse brush appeared for wire positive at 9850. This brush became brighter at its point as the voltage was increased, changing over into a uniform continuous glow at 10880 . When the voltage was lowered again, the brush would again appear.

At 11440 a flickering glow appeared along the wire when negative. This glow was purple and diffuse, and accompanied by a strong smell of ozone.

2/4/14

TABLE 12.

#20 B. & S. Copper Wire - Diameter 0.77 mm.

Temperature	26.2°C.
Relative Humidity	34.1%
Barometric Pressure	746.9 mm.

	+	-
Critical Voltage	11850	12075
Visible Glow	11850	12400

P.D.	Galv. defl. in mm.		Shunt Factor		Current in 10^{-4} amp.	
	+	-	+	-	+	-
12075	89.3	3.0	110.9	1.0	0.285	0.000086
12400	190.0	10.0	110.9	110.9	0.606	0.319
12950	34.3	25.3	1109.0	1109.0	1.10	0.808
14000	67.7	65.0	1109.0	1109.0	2.16	2.08
14700	119.7	117.5	1109.0	1109.0	3.82	3.75

Figure of merit of galvanometer 2.88×10^{-9} amp. per mm.

2/4/14

TABLE 13.

#18 B. & S. Copper Wire - Diameter 1.025 mm.

Temperature	26.4°C.
Relative Humidity	30.9%
Barometric Pressure	746.9 mm.

	+	-
Critical Voltage	13500	14040
Visible Glow	13500	14120

P.D.	Galv. defl. in mm.		Shunt Factor		Current in 10^{-4} amp.	
	+	-	+	-	+	-
14000	180.0	3.0	110.9	1.0	0.575	0.000086
14450	37.0	26.2	1109.0	1109	1.18	0.836
14700	52.7	47.8	1109.0	1109	1.68	1.53

Figure of merit of galvanometer 2.88 x 10^{-9} amp. per mm.

#16 B. & S. Copper Wire - Diameter 1.285 mm.

Temperature	27.2°C.
Relative Humidity	29.0%
Barometric Pressure	746.9 mm.

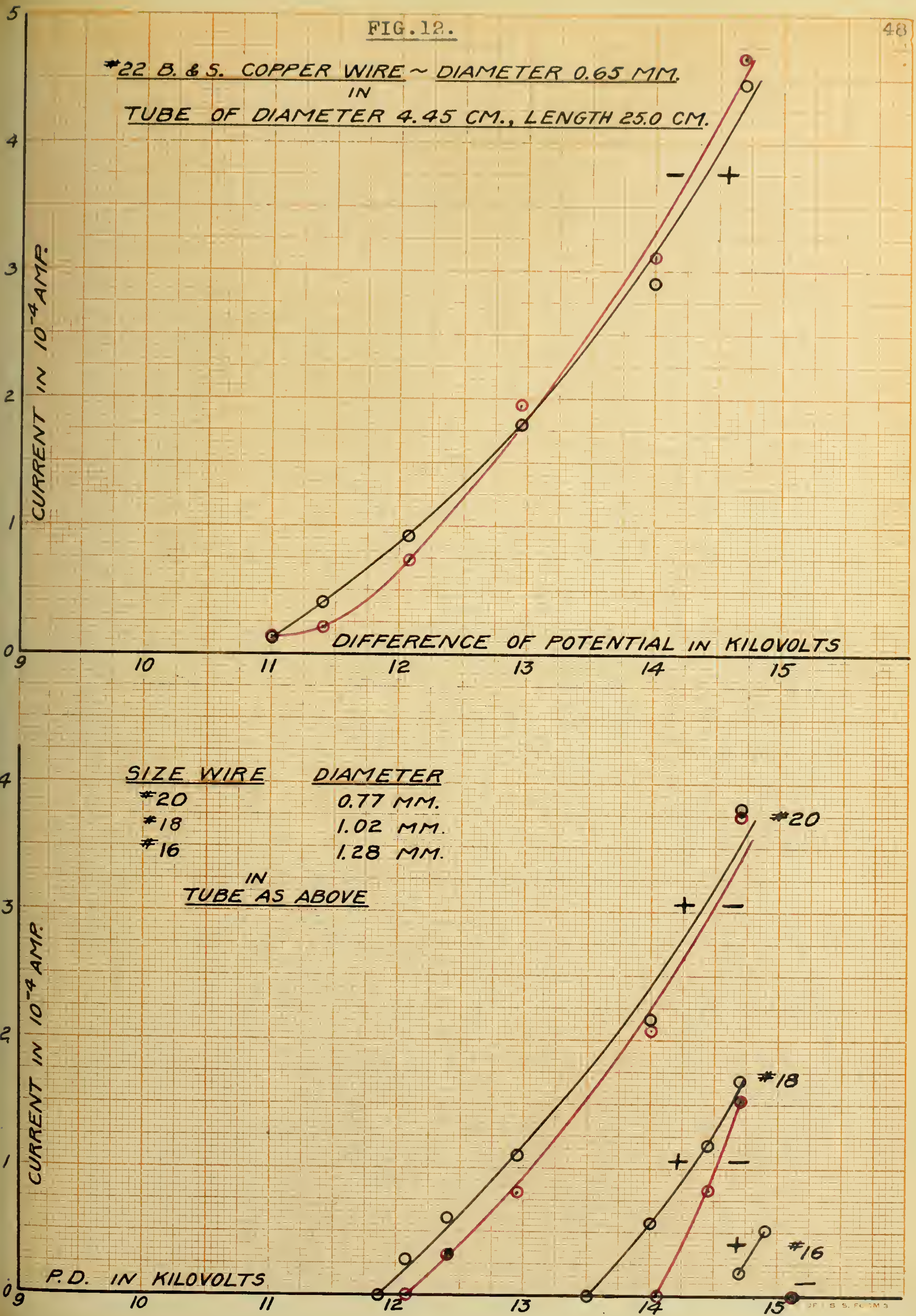
	+	-
Critical Voltage	14700	15220
Visible Glow Glow	14700	15220

P.D.	Galv. defl. in mm.		Shunt Factor		Current in 10^{-4} amp.	
	+	-	+	-	+	-
14700	61.3	3.0	110.9	1.0	.196	.000086
14800	161.7	4.0	110.9	1.0	.516	.000115

Figure of merito of galvanometer 2.88 x 10^{-9} amp. per mm.

2/4/14

FIG. 12.



#22 B. & S. COPPER WIRE ~ DIAMETER 0.65 MM.
IN
TUBE OF DIAMETER 4.45 CM., LENGTH 25.0 CM.

SIZE WIRE	DIAMETER
#20	0.77 MM.
#18	1.02 MM.
#16	1.28 MM.

IN
TUBE AS ABOVE

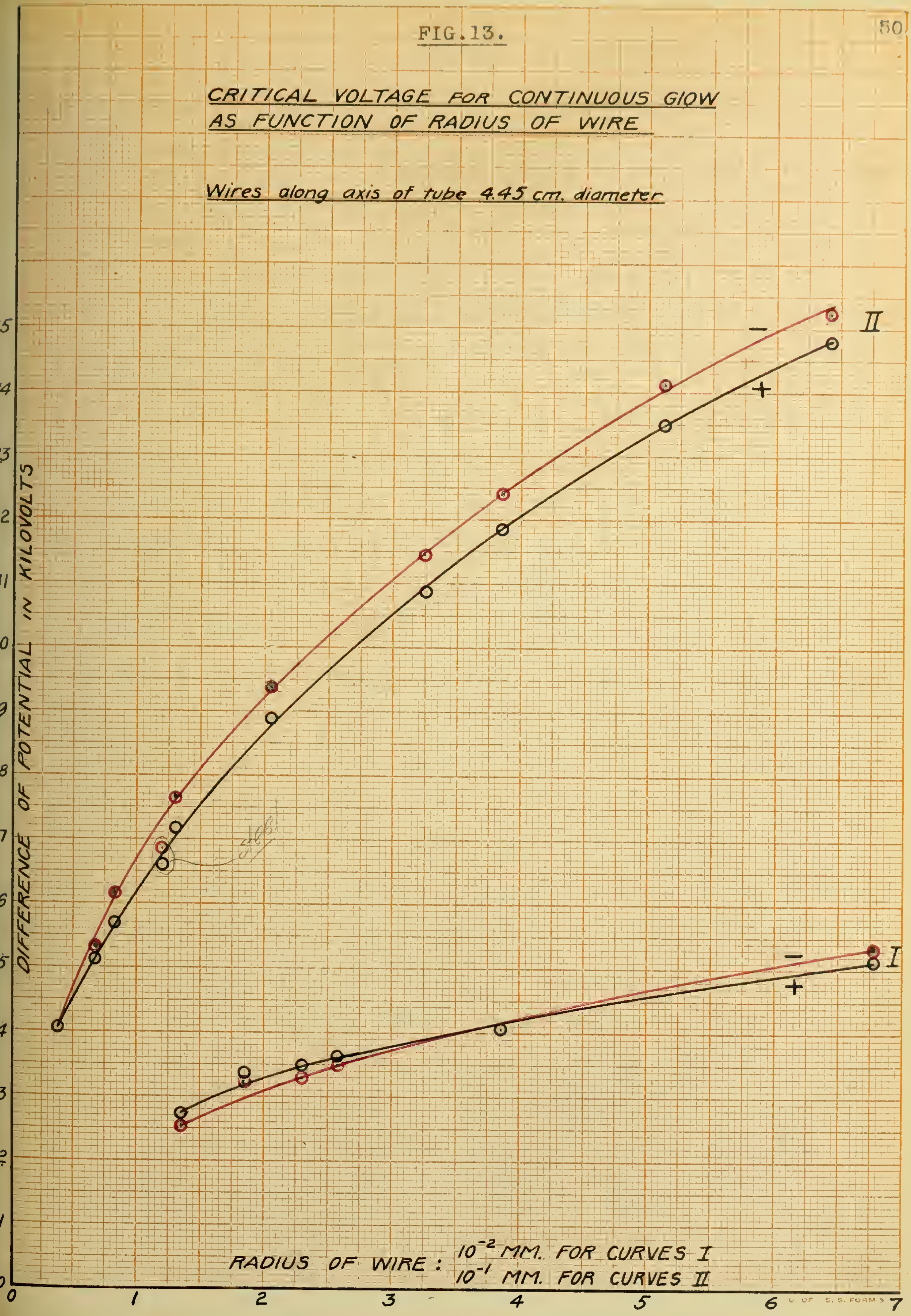
TABLE 14.

Critical Difference of Potential to Cause Continuous Glow as Function of Radius of Wire

Radius in mm.	Material	Positive	Negative
0.0135	Silver	2720	2520*
0.0185	Silver	3330	3230*
0.0230	Tungsten	3500	3300
0.0253	Silver	3630	3500
0.0386	#40 Copper	4060	4060
0.0678	#36 Copper	5140	5320
0.0825	#34 Copper	5710	6140
0.120	Steel "E" String	6600	6840
0.130	#30 Copper	7180	7660
0.205	#26 Copper	8900	9370
0.325	#22 Copper	10880	11440
0.385	#20 Copper	11850	12400
0.512	#18 Copper	13500	14120
0.642	#16 Copper	14700	15220

*These values uncertain on account of dimness of glow.

FIG. 13.



CRITICAL VOLTAGE FOR CONTINUOUS GLOW AS FUNCTION OF RADIUS OF WIRE

Wires along axis of tube 4.45 cm. diameter

--Chapter V--

Factors Affecting the Coronal Current

Section 1: Pressure.

The effect of variation of pressure on the voltage to cause continuous glow was studied for a #26 wire by varying the pressure in the tube from 768 mm. down to 2 mm. and the results are given in Table 15 and shown by curves in Fig.14. Below about 20 mm. pressure it was found impossible to get a negative uniform glow. Instead of this there appeared a series of beads approximately equally spaced along the wire. This discontinuous distribution of brushes or beads on the wire when negative was investigated later and the discussion of this phenomenon is reserved for a later chapter.

It was found that measurements of the coronal current for the same wire gave different results on different days and it was considered advisable to find out the influence of pressure for a range around atmospheric pressure in order that the current readings for the different sizes of wire might be reduced to a 760 mm. basis. Therefore a series of characteristic curves was taken for different pressures with dry air in the tube to do away with any effect which might be due to the moisture in the air. Table 17 and Fig.16. show the results obtained. These curves show a marked increase in the current for a

TABLE 15.

Variation of Critical Voltage With Pressure

#26 B. & S. Copper Wire - Diameter 0.41 mm.

Dry Air at 25°C.

Pressure in mm.	P. D. for Continuous Glow	
	+	-
2.0	720	*580
10.9	940	*870
18.9	1110	1200
53.2	1770	1920
91.3	2350	2580
173.5	3450	3750
248.5	4250	4610
334.8	5120	5520
483.6	6660	7120
616.6	7800	8330
720.0	8730	9210
746.0	8980	9530
768.3	9100	9640

*No continuous glow obtainable - voltage is that of formation of beads.

2/18&19/14

FIG. 14.

VARIATION OF CRITICAL VOLTAGE WITH PRESSURE

*26 B. & S. Copper Wire ~ Diameter 0.41 mm.
in
Tube of Length 25.0 cm., Diameter 4.45 cm.
Dry Air in Tube.

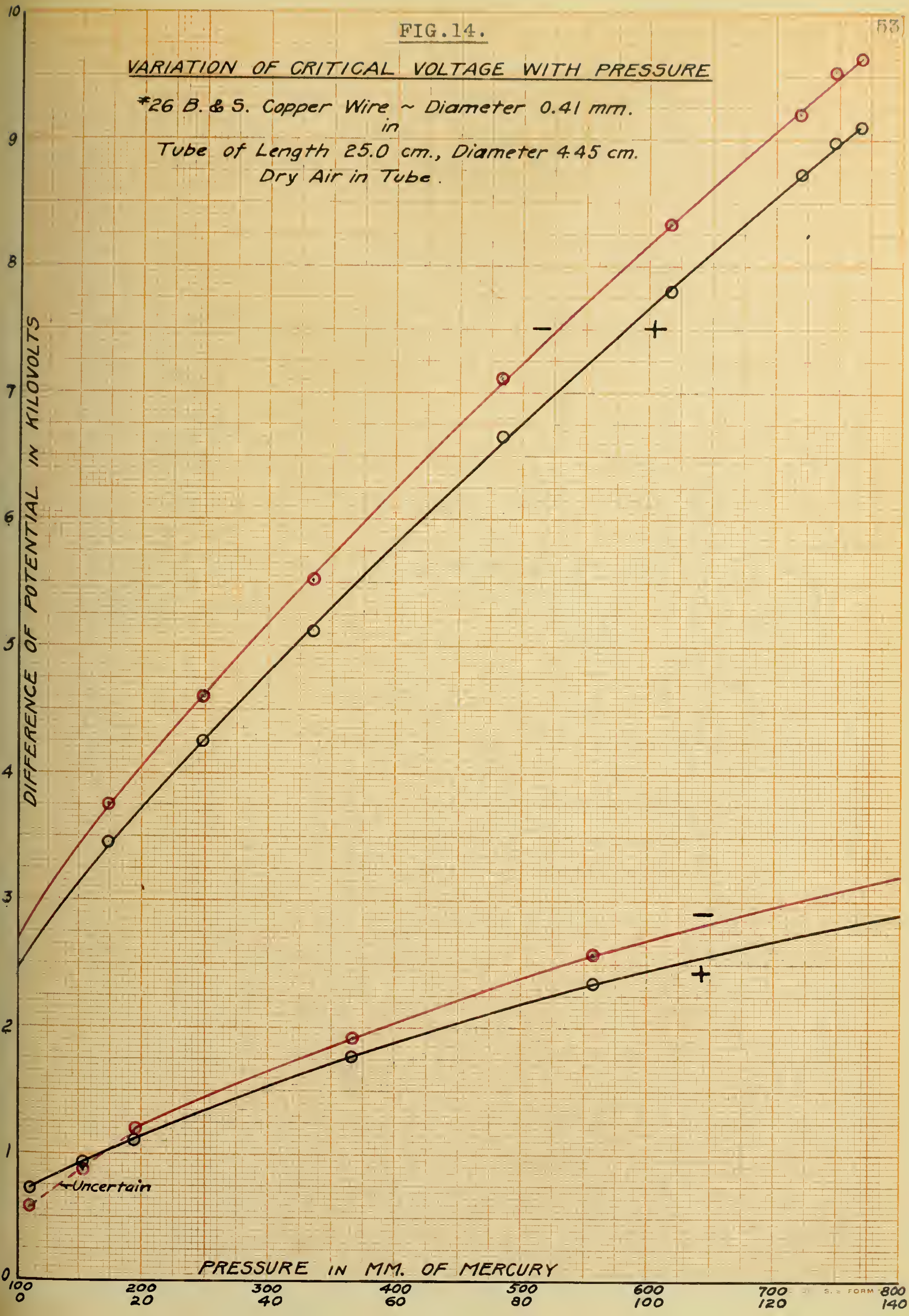


TABLE 17.

Influence of Pressure Upon Current

#26 B. & S. Wire - Diameter 0. 41 mm.

in Closed Tube at 25°C.

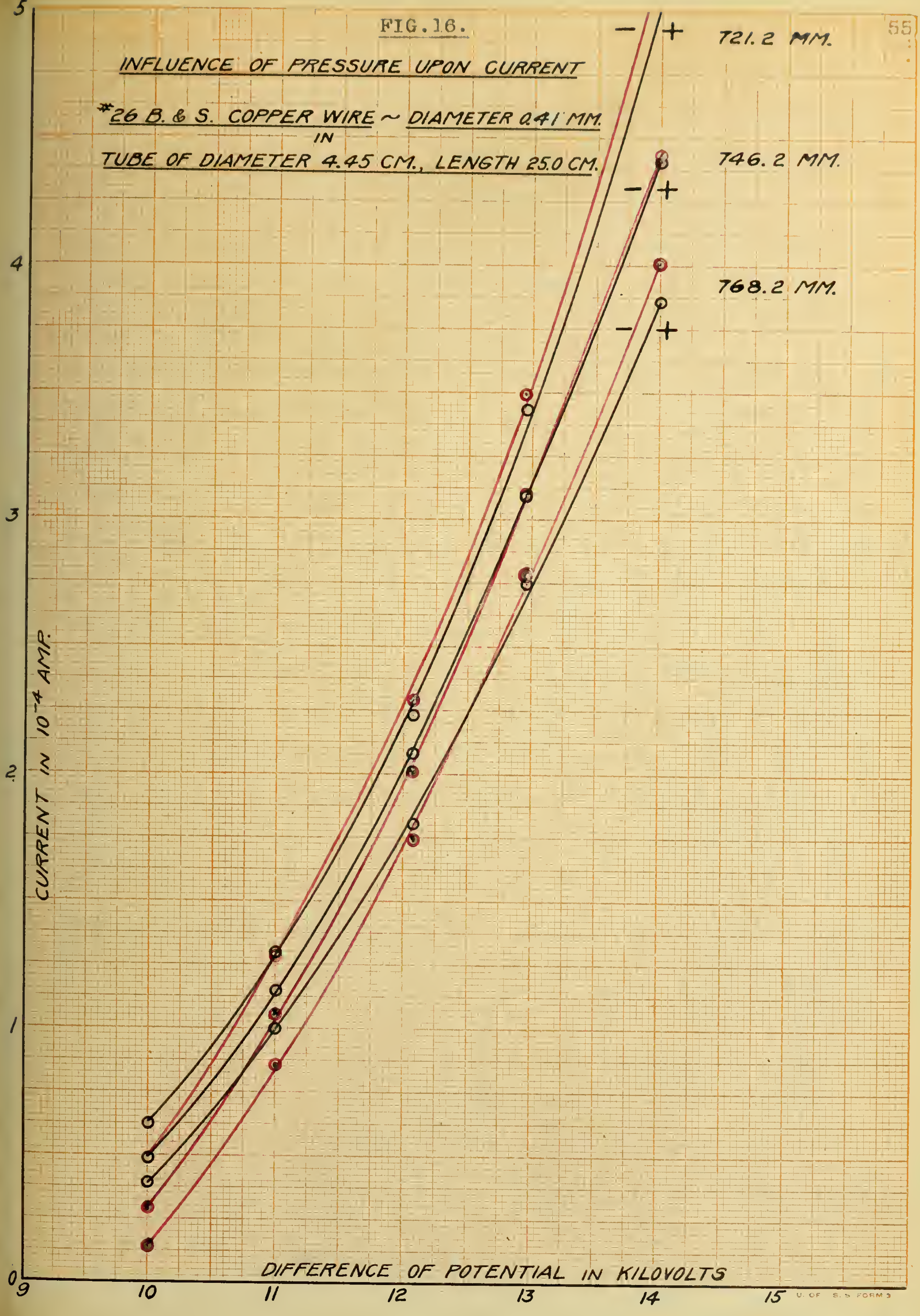
P.D.	Current in 10^{-4} amperes					
	721.25 mm.		746.2 mm.		768.2 mm.	
	+	-	+	-	+	-
10000	0.625	0.493	0.496	0.289	0.386	0.143
11000	1.30	1.28	1.15	1.06	1.00	0.856
12075	2.23	2.29	2.08	2.01	1.81	1.74
12950	3.43	3.49	3.09	3.11	2.75	2.78
14000	5.03	5.20	4.41	4.43	3.86	4.01

Test run in direction of increasing pressure.

Dry air in tube.

2/18/14.

FIG. 16.



INFLUENCE OF PRESSURE UPON CURRENT

*26 B. & S. COPPER WIRE ~ DIAMETER 0.41 MM.
IN
TUBE OF DIAMETER 4.45 CM., LENGTH 25.0 CM.

relatively small decrease in the pressure. The curves also show an unsymmetrical spacing ~~of the curves~~ which suggests the presence of some disturbing factor. In order to ascertain whether the effect of varying pressure would be the same for a smaller wire and also discover whether there would again be a disturbance of the curves, a similar test was run on a #36 wire. The results are given in Table 18. On plotting these results it was found that the disturbance of the curves was more marked and the apparent variation for change of pressure showed no regularity whatever. In order to check any errors which might be due to mistakes in the determinations, the test was repeated with the utmost care. The disturbance still persisted but was much less for the curves taken with the wire positive than for those with the wire negative. This last test is shown in Table 18.

These results made it evident that it was useless to try in this manner to find any factors which might be applied to the data taken earlier in the year in order to reach a 760 mm. basis. Peek reduces his data on the alternating current corona to a 760 mm. and 25 deg. C. basis and it was desired to reduce the data of this investigation to the same basis in order to make comparisons between results possible. Finally it was planned to carry out a series of tests upon different size wires in the tube with the pressure kept constant at 760 mm. and a temperature of 25 deg. C. Such a test was run on a silver wire of diameter .0517 in diameter. An ascending and descending series of readings was taken and it was found that the results differed for increasing and decreasing currents. Table 19 shows these results and it will be noted that for the lower voltages the agreement is poor between

TABLE 18. continued

Influence of Pressure Upon Current

≠36 B. & S. Wire - Diameter 0.135 mm.

in Closed Tube at 25°C.

Test No. 2

Current in 10^{-4} amperes

P.D.	720 mm.		740 mm.		760 mm.		780 mm.	
	+	-	+	-	+	-	+	-
5950	0.154	0.224	0.135	0.133	0.120	0.120	0.109	0.107
7000	0.439	0.611	0.446	0.481	0.439	0.450	0.387	0.442
8000	0.930	1.16	0.936	1.04	0.899	0.985	0.851	0.962
9100	1.57	1.82	1.60	1.67	1.56	1.66	1.43	1.55
10000	2.27	2.57	2.21	2.37	2.15	2.35	2.08	2.21
11000	3.19	3.45	3.12	3.33	3.04	3.27	2.96	3.07
12075	4.19	4.61	4.26	4.49	4.16	4.36	4.00	4.22
12950	5.33	5.92	5.33	5.68	5.25	5.59	5.14	5.36
14000	--	--	--	--	6.61	7.26	--	--

Test run in direction of increasing pressure.

Dry air in tube.

4/16/14

TABLE 19

Silver Wire - Diameter 0.517 mm.

In Closed Tube at 760 mm. Pressure Ascending and Descending Series

Temperature 25.0°C.

Humidity 50.0%

	+		-	
	Start	Finish	Start	Finish
Critical Voltage	3600	3700	3500	3650
Visible Glow	3650	3800	3600	3650

P.D.	+ Current in 10^{-4} amp. Up	Down	- Current in 10^{-4} amp. Up	Down
3650	0.0095	0.0032	0.013	0.00065
3860	0.0286	0.019	0.039	0.027
4920	0.201	0.217	0.312	0.270
5950	0.514	0.553	0.735	0.670
7000	1.00	---	1.23	---
8000	1.62	1.56	1.87	1.81
9100	2.31	---	2.59	---
10000	2.98	2.97	3.38	3.35
11000	4.05	---	4.27	---
12075	5.27	5.27	5.72	5.79
12950	6.70	6.70	7.29	7.29

4/20/14

the ascending and the descending readings. The tube was then opened to the atmosphere, the air inside it renewed and a similar set of readings was taken for atmospheric pressure. The agreement for the ascending and descending series was much better than when the air was confined. These results are given in Table 4 and Fig.17. gives a comparison between the two series of tests. It is very evident from these curves that the difference between the positive curves is very much smaller than that between the negative curves. It was impossible to determine from the data at hand whether this dissimilar effect on the two polarities was strictly a pressure effect or whether the condition of the air in the tube had something to do with it.

In order to do away with any disturbing effects due to moisture in the air and possible changes in the constitution of the air in the tube, an arrangement was devised for supply-dry air which could be pumped through the tube out into the atmosphere. The air was dried by passing it through a couple of wash-bottles containing concentrated sulphuric acid and then through a tube containing soda-lime. A #40 wire was strung in the tube and as the atmospheric pressure varied from day to day series of readings were taken as given in Table 21. The general decrease of current with increase of pressure is apparent. The readings for the extreme pressures 735 mm. and 754 mm. are shown in Fig.18. These curves show quite a regular variation in the effect of pressure with a tendency toward a greater effect upon the current for negative polarity. This regularity would seem to indicate that the discordant results obtained in the other pressure experiments were due to the presence of other factors than mere change of the pressure.

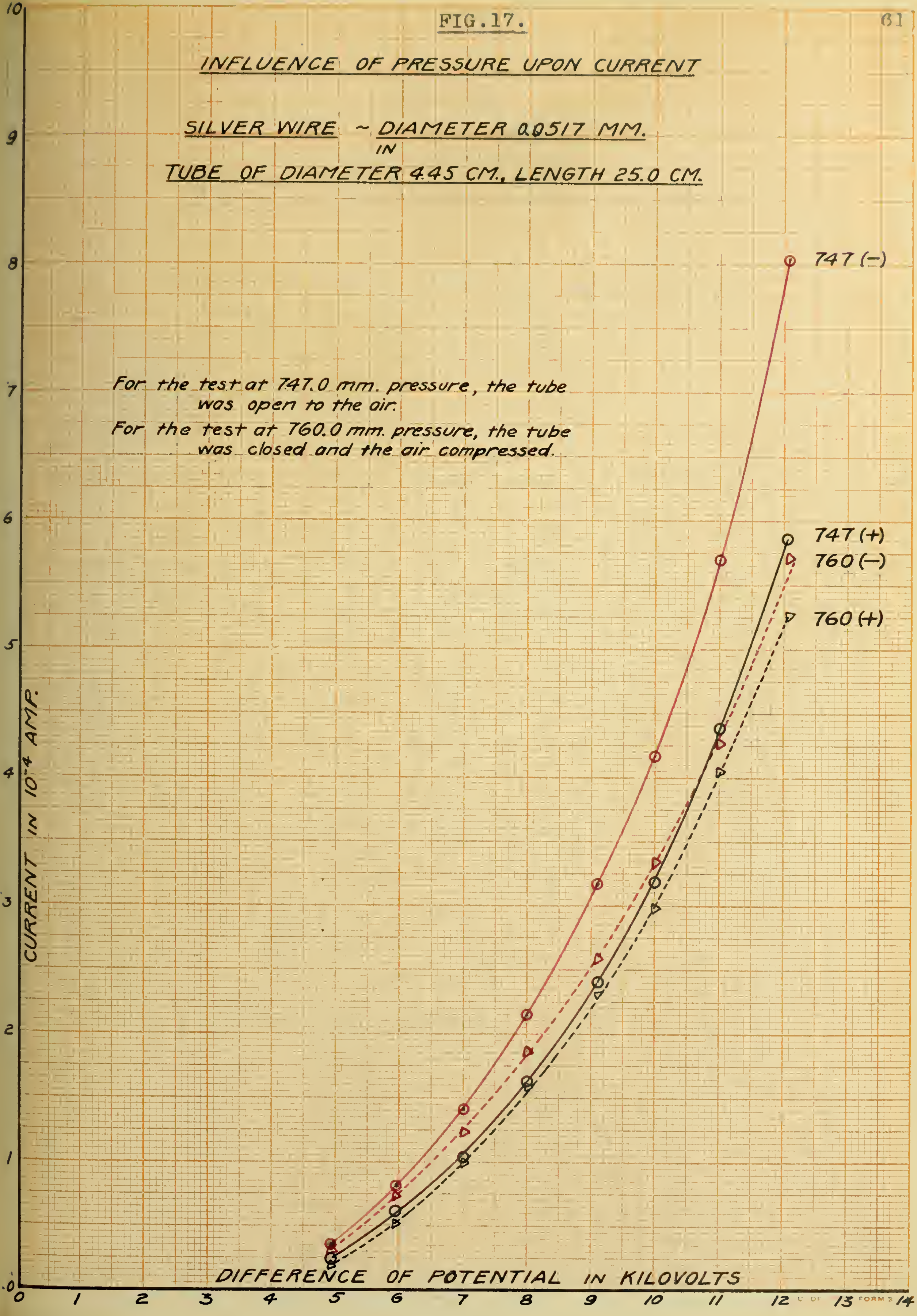


FIG. 17.

INFLUENCE OF PRESSURE UPON CURRENT

SILVER WIRE ~ DIAMETER 0.0517 MM.
IN
TUBE OF DIAMETER 4.45 CM., LENGTH 25.0 CM.

For the test at 747.0 mm. pressure, the tube was open to the air.

For the test at 760.0 mm. pressure, the tube was closed and the air compressed.

TABLE 21.

Effect of Pressure

#40 B. & S. Copper Wire - Diameter 0.077 mm.

in

Tube of Diameter 4.45 cm. - length 25.0 cm.

Dry Air in Tube

Currents in 10^{-4} amp.

P.D.	735 mm.		738 mm.		749.0		754.0	
	+	-	+	-	+	-	+	-
3860	.00025	.00030	.000076	.000051	.000015	.000015	.000015	.000015
4920	0.205	0.176	0.181	0.210	0.150	0.169	0.150	0.169
5950	0.553	0.676	0.557	0.703	0.468	0.611	0.468	0.602
7000	1.06	1.34	1.06	1.35	0.859	1.17	0.900	1.16
8000	1.76	2.28	1.73	2.32	1.38	1.90	1.53	2.02
9100	2.58	3.35	2.53	3.25	2.15	2.86	2.28	2.90
10000	3.45	4.49	3.43	4.52	2.81	3.71	2.99	3.77
12075	6.24	7.64	6.15	8.16	5.17	6.51	5.40	6.83

Positive Corona Appearance

+	735	738	749	754
Jump	4080	4100	4100	4100
Visible	4150	4160	4110	4150

Figures for 738.0 mm. are average of three tests

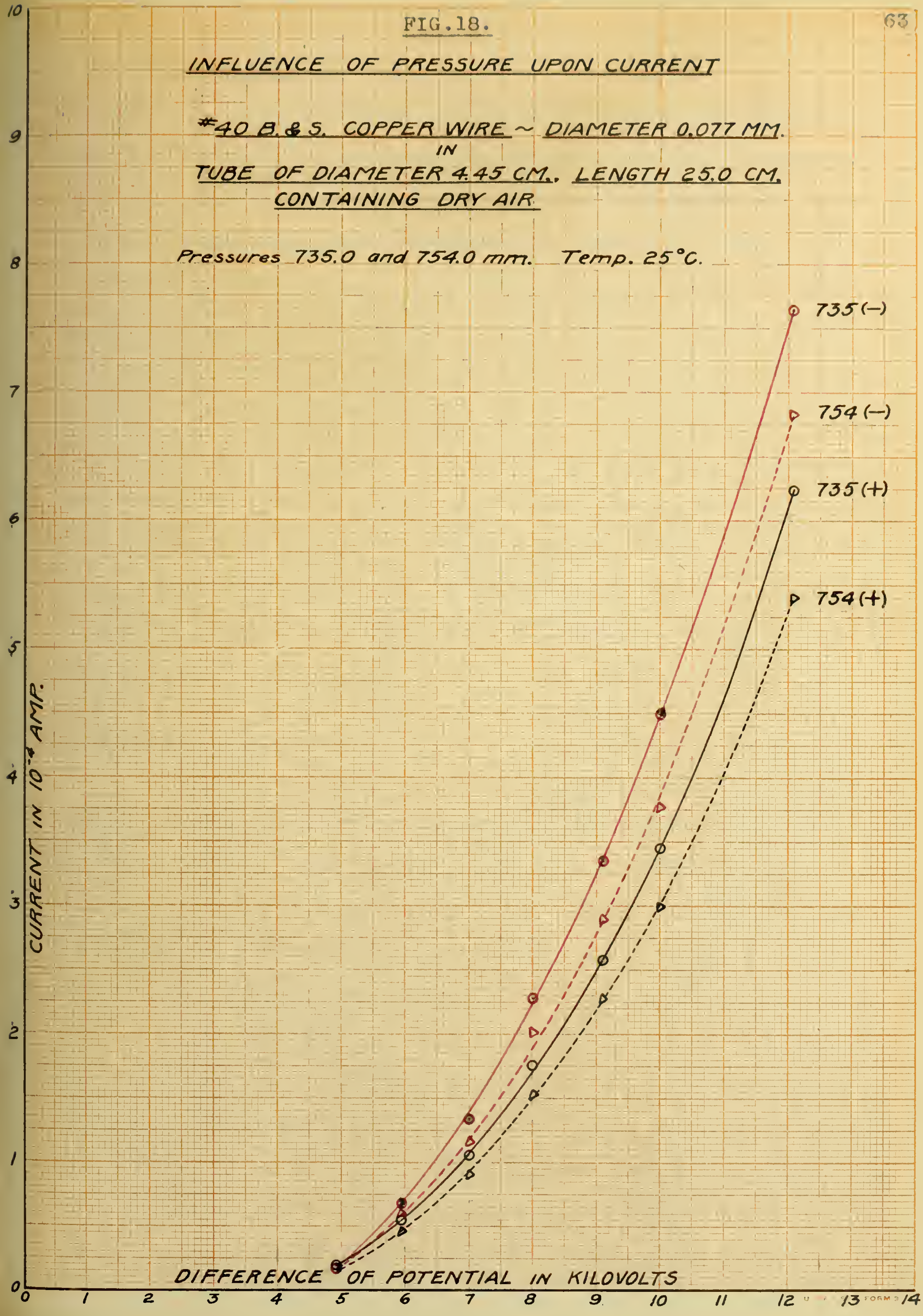
4/24/14 to 5/4/14

FIG. 18.

INFLUENCE OF PRESSURE UPON CURRENT

#40 B. & S. COPPER WIRE ~ DIAMETER 0.077 MM.
IN
TUBE OF DIAMETER 4.45 CM., LENGTH 25.0 CM.
CONTAINING DRY AIR

Pressures 735.0 and 754.0 mm. Temp. 25°C.



Section 2: Condition of the Air.

To determine what effect, if any, the confining of air in a closed tube had upon the coronal current a series of tests was run under constant pressure with various conditions as to the closing of the tube, the renewal of the air etc. These conditions are given in Table 20 as well as the numerical results. These results indicate that confinement of the air has a great effect upon the coronal current and also upon the critical and visible glow voltages. Such an effect does not appear strange when one thinks of the quantities of ozone formed and possibly other products, which when the tube is closed must remain inside and thus change the character of the gas to a considerable extent. It must be concluded from these tests that it is unsafe to compare results obtained in a closed tube with those obtained where there is a plentiful supply of fresh air.

Section 3: Moisture.

In connection with the apparatus for the supply of dry air to the tube, an arrangement was devised whereby air could be drawn from the room thru the tube. The humidity of such air was given by calculation from the readings of wet and dry bulb thermometers. Parallel sets of readings were taken from day to day of the current flowing when dry air was pumped continuously thru the tube and when air from the room was sucked thru before each reading. The readings are given in Table 22, and the comparative characteristics for 735 mm. pressure and relative humidity 69% are shown in Fig.19. These curves indicate a regular effect due to moisture, with a tendency for the decrease of current by humidity to be greater for negative polarity of the wire.

TABLE 20.

Variation of Current with Condition of Air

Silver Wire - Diameter .0517 mm.

Temperature	25.0°C.
Humidity	48.0%
Barometric Pressure	748.0

Ascending and Descending Series Run Under Following Conditions

1 Tube completely closed and air not changed

2 Holes open at ends - air renewed before test and afterward unchanged

3 Holes open and air from room pumped continuously through tube.

Appearance of Positive Corona

	Series 1		Series 2		Series 3	
	Up	Down	Up	Down	Up	Down
Critical Voltage	3670	3200	3200	3150	3150	3300
Visible Glow	3840	3740	3760	3760	3860	3760

4/21/14

TABLE 20. continued

Variation of Current with Condition of Air

WIRE POSITIVE

PD	(1) Tube closed			(2) Open: air not renewed		(3) Open: air renewed	
	Up	Down	Up	Up	Down	Up	Down
3860	0.0143	0.0462	0.0463	0.0625	0.067	0.0535	0.0455
4920	0.208	0.316	---	0.353	---	0.351	---
5950	0.553	0.725	0.686	0.820	0.904	0.746	0.780
7000	0.779	---	---	1.43	---	1.33	---
8000	1.69	1.98	1.89	2.28	2.21	2.02	2.14
9100	2.56	---	---	3.28	---	2.91	---
10000	3.31	3.53	3.63	4.10	4.36	3.90	4.16
11000	4.62	4.81	---	5.50	---	5.20	---
12075	6.02	6.02	6.60	7.35	7.35	6.90	6.90

WIRE NEGATIVE

PD	(1)			(2)		(3)	
	Up	Down	Up	Up	Down	Up	Down
3860	0.0202	0.0664	0.0657	0.0938	0.0996	0.0670	0.0469
4920	0.319	0.404	---	0.521	---	0.501	---
5950	0.754	0.918	0.911	1.11	1.03	0.976	1.07
7000	1.29	---	---	1.89	---	1.70	---
8000	1.98	2.31	2.40	3.19	2.69	2.74	2.93
9100	2.93	---	---	3.78	---	3.97	---
10000	3.88	4.16	4.59	5.16	5.15	5.27	5.27
11000	5.34	5.57	---	6.64	---	6.84	---
12075	7.16	7.16	7.49	8.72	8.72	9.25	9.25

TABLE 22.

Effect of Moisture

#40 B. & S. Copper Wire - Diameter 0.077 mm.

in

Tube of Diameter 4.45 cm. - Length 25.0 cm.

Temperature 25.0°C

Currents in 10^{-4} amp.

P.D.	738.0 mm. + Dry	738.0 mm. + 68% Humidity	738.0 mm. - Dry	738.0 mm. - 68% Humidity	738.0 mm. + Dry	738.0 mm. + 63% Humidity	738.0 mm. - Dry	738.0 mm. - 63% Humidity
3860	--	--	--	--	.000076	--	.000051	--
Critical Voltage	3960.	3980.	--	--	4000	4080	--	--
Visible Glow	3980.	4060.	3980.	3980	4060	4110	--	--
4920	0.189	0.150	0.202	0.174	0.176	0.135	0.247	0.185
5950	0.553	0.464	0.715	0.592	0.553	0.455	0.715	0.566
7000	1.05	0.895	1.37	1.09	0.995	0.884	1.31	1.08
8000	1.76	1.56	2.41	1.89	1.66	1.50	2.21	1.86
9100	--	--	--	--	2.52	2.31	3.25	2.86
10000	3.51	3.21	4.88	3.77	3.35	3.10	4.16	3.84
12075	6.18	5.86	8.45	6.76	6.13	5.73	7.87	7.06

TABLE 22. continued

Effect of Moisture

P.D.	735.0 mm.				754.0 mm.			
	+		-		+		-	
	Dry	69% Humidity	Dry	69% Humidity	Dry	38% Humidity	Dry	38% Humidity
3860	.00025		.000076	.00076	.000015		.000015	
Critical Voltage	4080.	4070.	--	--	4100.	4130.	--	--
Visible Corona	4150	4120	--	--	4150.	4150.	--	--
4920	0.205	0.138	0.176	0.174	0.150	0.124	0.169	0.152
5950	0.553	0.455	0.676	0.566	0.468	0.460	0.602	0.546
7000	1.06	0.898	1.34	1.14	0.900	0.891	1.16	1.07
8000	1.76	1.55	2.28	1.96	1.53	1.54	2.02	1.76
9100	2.58	2.34	3.35	2.88	2.28	2.31	2.90	2.60
10000	3.45	3.16	4.49	3.95	2.99	3.03	3.77	3.42
12075	6.24	5.73	7.64	6.83	5.40	5.40	6.83	6.00

4/24/14 - 5/4/14

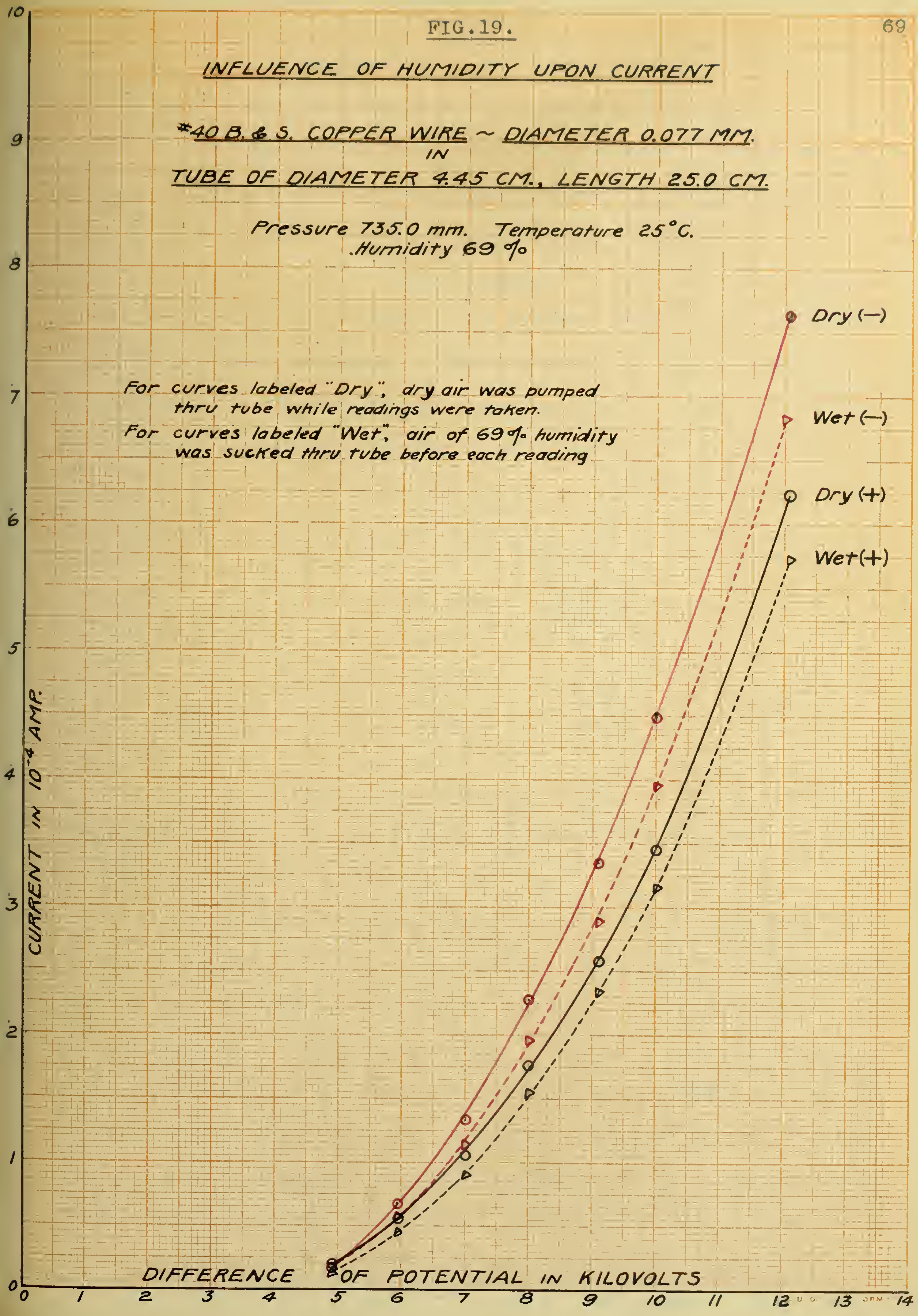


FIG.19.

INFLUENCE OF HUMIDITY UPON CURRENT

*40 B. & S. COPPER WIRE ~ DIAMETER 0.077 MM.
IN
TUBE OF DIAMETER 4.45 CM., LENGTH 25.0 CM.

Pressure 735.0 mm. Temperature 25°C.
Humidity 69 %

For curves labeled "Dry", dry air was pumped thru tube while readings were taken.

For curves labeled "Wet", air of 69% humidity was sucked thru tube before each reading.

The decrease of current by the presence of moisture is well known and these results bear out this effect.

To determine whether the presence of moisture in the air has an effect upon the critical voltage, a test was run as follows under a pressure of 736 mm. and humidity 68.5%:

Air was sucked through the tube from the room and the voltage was noted at which the initial jump of the galvanometer occurred for wire positive. Then the positive glow voltage was determined and next the negative glow voltage. Then dry air was pumped through the tube and the same measurements were taken. An average of two sets of readings on the uncalibrated low scale of the Kelvin voltmeter gave the results:

	Wet Air	Dry Air
Positive crit.v.	4300	4190
" glow v.	4350	4260
Negative " v.	4275	4370

The effect of moisture is then to raise somewhat the starting point of the positive corona and act in the opposite way for the opposite polarity.

With wire negative and moist air in the tube, the discharge begins from dim spots and the discharge is of no clearly defined nature, being a mixture of sections of continuous glow and bright spots, these spots being immobile. The discharge begins quite differently for the same polarity and dry air. As the voltage is increased, suddenly a bright spot will appear. Then for increasing voltage a number of spots appear and they are regularly spaced, increasing in number with the voltage. These brushes are in continual movement back and forth.

The effect of moisture on the appearance of the negative discharge was shown by the following experiment:

The tube was filled with moist air and a voltage somewhat above the critical value was impressed. A mixed discharge resulted as described above. Then a current of dry air was started through the tube and little by little the discharge cleared up and resolved itself into a line of uniformly spaced brushes which were in continual agitation. If moist air were again admitted, the discharge resumed its former character.

With moist air in the tube and a fairly high P.D. the wire vibrates circularly for both polarities, describing a torpedo-like figure of revolution. The filling of the tube with dry air diminishes considerably the amplitude of the vibration for wire positive and stops the vibration entirely for wire negative.

Section 4: Temperature.

The influence of temperature upon the current for a #36 wire in a closed tube under a pressure of 760 mm. was determined for the range from 15 deg. to 25 deg. C. and the results appear in Table 16 and Fig.15. The lower temperature was obtained by placing cloths wet with alcohol upon the tube and directing a stream of air from a fan upon it. The curves indicate that this difference of temperature makes far more difference in the current for wire negative than for wire positive, both currents showing an increase for increasing temperature as might be expected.

Section 5: Material of Wire.

An attempt was made to determine the effect of the character of the surface and the material of the wire in the following way. A characteristic curve was obtained for a bright new

TABLE 16.

Influence of Temperature Upon Current

#36 B. & S. Wire - Diameter 0.135 mm.

in Closed Tube at 760 mm. pressure

P.D. for Continuous Glow

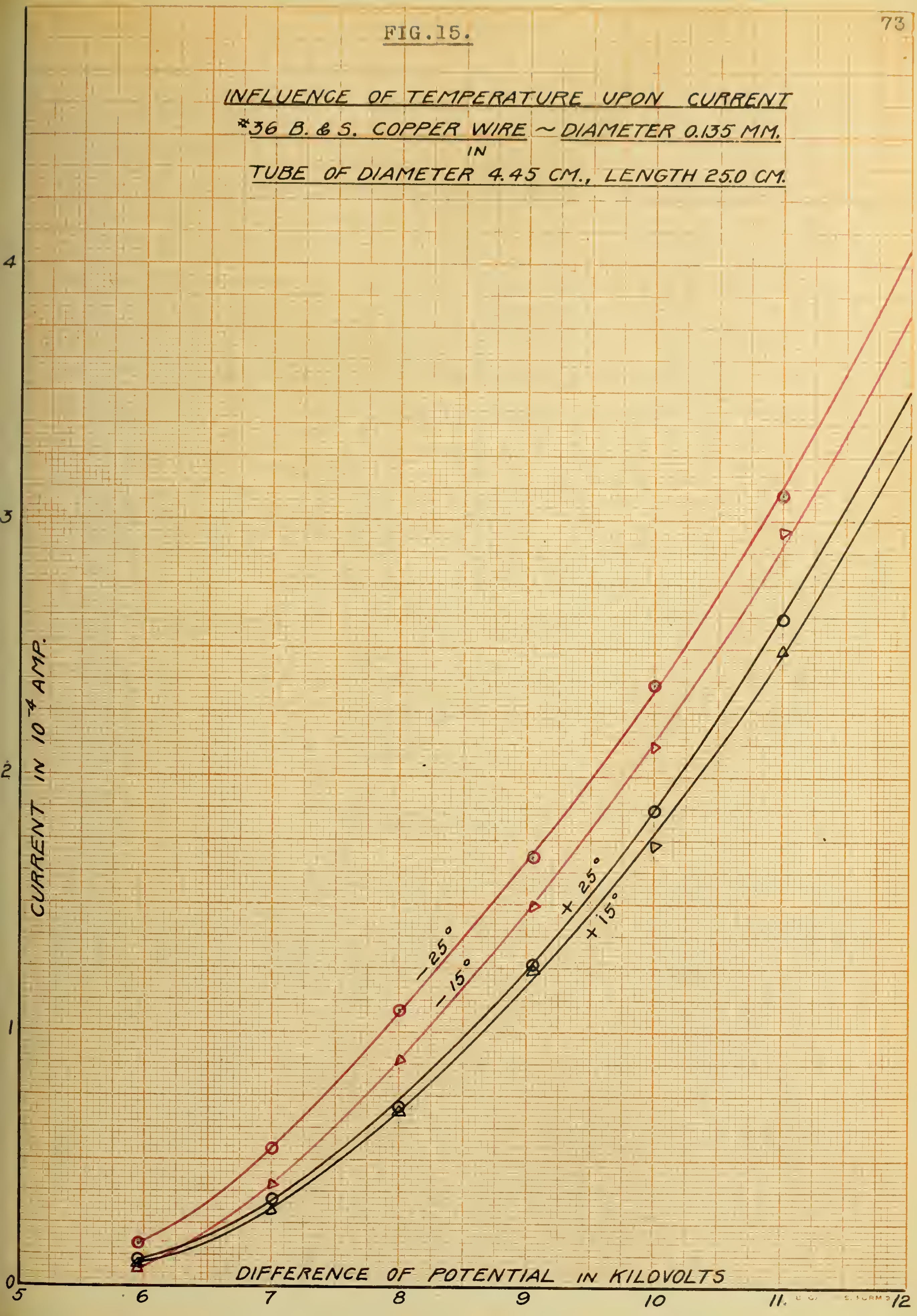
	15°C.	25°C.
+	5340	5200
-	5760	5680

Current in 10^{-4} amperes.

P.D.	15°C.		25°C.	
	+	-	+	-
5950	0.0809	0.0745	0.122	0.174
7000	0.308	0.405	0.347	0.542
8000	0.696	0.890	0.710	1.085
9100	1.24	1.49	1.27	1.68
10000	1.73	2.12	1.87	2.36
11000	2.49	2.96	2.62	3.10
12075	3.40	4.05	3.70	4.14

4/11/14

FIG.15.


INFLUENCE OF TEMPERATURE UPON CURRENT
*36 B. & S. COPPER WIRE ~ DIAMETER 0.135 MM.
IN
TUBE OF DIAMETER 4.45 CM., LENGTH 25.0 CM.
CURRENT IN 10⁻⁴ AMP.
DIFFERENCE OF POTENTIAL IN KILOVOLTS
0
1
2
3
4
5
6
7
8
9
10
11
12
−25°
−15°
+25°
+15°

steel mandolin "E" string in a tube open to the air. Then the wire was dipped into a solution of copper sulphate long enough to acquire a smooth coating of copper and another characteristic was obtained. Then this wire was amalgamated and another test run. A piece of the same wire was dipped into nitric acid long enough to roughen it without appreciably decreasing its diameter and a test was run on it. Small differences were found to exist in the characteristics but these differences were accountable for by the changes in humidity and pressure during the time of running the series of tests.

Section 6: Magnetic Field.

A strong electromagnet was arranged with its poles in close proximity to a tube containing a wire on which there was corona and no effect upon the current or the appearance of the discharge could be detected, both for discharges at atmospheric pressure and reduced pressures.

* * *

Of course diameter of wire and voltage are also factors influencing the coronal current, but they have been discussed elsewhere and hence are simply mentioned here.

--Chapter VI--

Pressure Due to Ionization

During the first set of experiments to determine the influence of the pressure upon the coronal current for pressures around atmospheric it was noticed that when the P.D. was applied the manometer connected to give the pressure inside of the tube showed a sudden increase of pressure. This sudden increase was most noticeable for the highest pressure and amounted to a centimeter or more. Since it was desired to keep the pressure in the tube constant a carboy was connected to the tube to act as an reservoir of large capacity and prevent the increase of pressure from reaching any noticeable value.

To investigate the connection between this increase of pressure and the P.D. impressed, a sensitive U-tube open manometer was constructed. The manometer had a bore of 2.8 mm. and contained a light mineral oil of specific gravity 0.859. It was connected to the tube, the pressure in the tube was adjusted to atmospheric, the tube was sealed up and the sudden increase of pressure was noted for voltages from those necessary to produce the coronae up to those causing the maximum jump the manometer would permit without forcing the oil out. The increases were not-

ed for both polarities of the wire. Table 23 contains data relative to the size of the wire and tube, the readings observed and the increases of pressures reduced to terms of millimeters of mercury. Fig.20 shows the increase of pressure plotted against P.D.

For the positive polarity of the wire, there was no appreciable increase of the pressure until the corona appeared. When the wire was negative, the presence of a small brush or two caused the level of the columns to differ appreciably before the general discharge appeared along the wire.

The jump for wire negative was greater than for wire positive for the greater part of the range of voltage and it will be seen that the general shape of the curves is the same as that of the characteristic curves for the same size of wire as given in Fig.8. Furthermore by comparing the numerical values of the currents and increases of pressure for like voltages it will be found that they are proportional. This shows that the increase is an ionization phenomenon, for if the sudden increase were due to the heating effect of the current we would expect the increases to vary as the square of the currents instead of the first power.

The theory of ionization would lead one to expect such a jump;when the gas is suddenly ionized the larger particles in the gas would be split up by collisions and each of the constituent parts would act as a separate molecule as far as its contribution to the total pressure is concerned.

This ionization pressure might serve as a principle upon which to build a high-tension voltmeter, for if such a tube were once calibrated, the indications of the manometer would give a measure of the P.D. impressed.

TABLE 23.

Pressure Due to Ionization

≠36 B. & S. wire. Tube 4.45 cm. internal diameter, 25 cm. long, volume 388 cu. cm.
Dry air in tube, pressure 744.0 mm., temp. 26°C.
Manometer bore 2.8 mm., containing mineral oil of .859 specific gravity.

Wire Positive					Wire Negative				
P.D.	Manometer - cm.			mm. of mercury	P.D.	Manometer - cm.			mm. of mercury
	Left	Right	Diff.			Left	Right	Diff.	
5340	Jump	barely	visible	0.000	4800	Jump	barely	visible	0.00
6180	12.22	13.30	1.08	0.682	6180	12.20	13.25	1.05	.664
6680	12.19	13.59	1.40	0.885	6700	11.98	13.50	1.52	.96
7080	11.72	13.82	2.10	1.33	7100	11.70	13.75	2.05	1.30
7440	11.48	14.10	2.62	1.66	7500	11.40	14.08	2.68	1.70
7820	11.00	14.56	3.56	2.25	7850	11.05	14.40	3.35	2.12
8200	10.80	14.79	3.99	2.52	8220	10.70	14.80	4.10	2.59
8620	10.36	15.20	4.84	3.06	8600	10.40	15.10	4.70	2.97
9200	9.75	15.80	6.05	3.83	8860	9.92	15.60	5.68	3.59
9800	9.0	16.5	7.5	4.74	9400	9.3	16.2	6.9	4.36
10400	8.3	17.3	9.0	5.69	10500	7.6	17.8	10.2	6.45
10840	7.4	18.1	10.7	6.76	11000	6.8	18.5	11.7	7.39
11300	6.6	18.8	12.2	7.71	11460	5.9	19.4	13.5	8.53
12200	4.8	20.3	15.5	9.80	11940	4.5	20.7	16.2	10.2
12900	3.3	22.1	18.8	11.9	12640	2.5	22.3	19.8	12.5
13840	1.1	24.3	23.2	14.7	13520	0.4	24.2	23.8	15.0
14200	0.2	25.2	25.0	15.5					

3/26/14

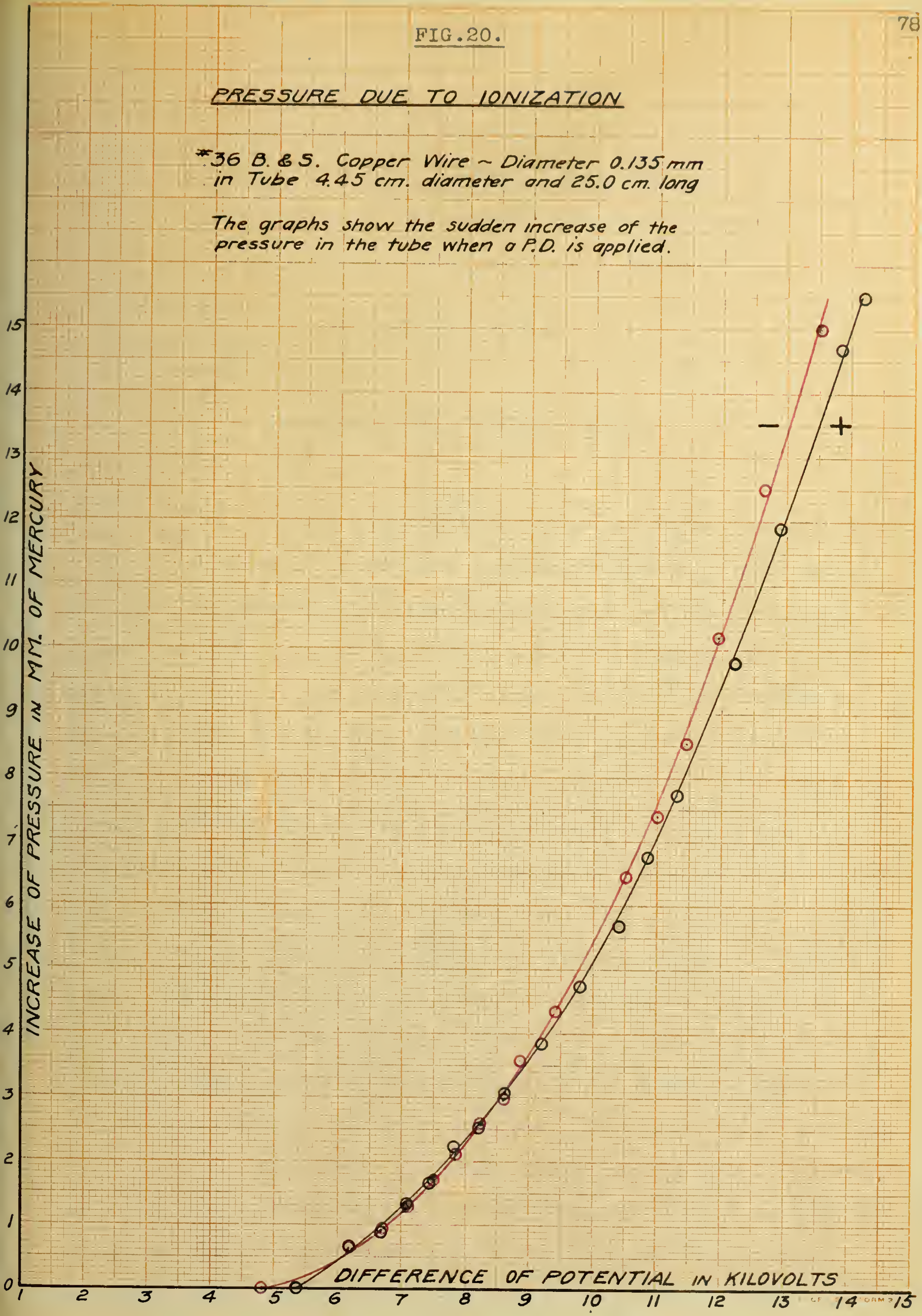


FIG.20.

PRESSURE DUE TO IONIZATION

*36 B. & S. Copper Wire ~ Diameter 0.135 mm in Tube 4.45 cm. diameter and 25.0 cm. long

The graphs show the sudden increase of the pressure in the tube when a P.D. is applied.

--Chapter VII--

Discontinuous Brush Discharge

It has already been mentioned in connection with a test to determine the effect of pressure upon critical voltage that for low pressures and negative polarity of the wire, the discharge took the form of isolated beads or brushes disposed with approximate regularity along the wire. In order to be able to see the wire broadside a glass tube was lined with a piece of sheet brass of such a width that a longitudinal slit was left along the tube and thus permit of inspection of the discharge along a central wire. The glass tube was closed at the ends by glass plates with central holes drilled through them. The wire passed through these holes and could be tightly stretched by means of a thumbscrew. The dimensions of the apparatus are given in Table 24 and Fig.21. is a photograph of it. This picture shows the branch tube through which the air could be exhausted and a wire along this tube connecting with the brass sheath. The holes around the wires where they passed through the glass plates were stopped by means of soft wax, the tube was exhausted and then filled with dry air by admitting air from the room thru the drying apparatus mentioned

TABLE 24.

#30 B. & S. Wire in Slit Tube

This test performed preliminary to taking photographs of various forms of discharge.

Diameter of wire 0.26 mm. Tube 3.5 cm. internal diameter, and 25 cm. long. Slit 0.6 cm. wide.

Tube closed, containing air of 39.1% humidity.

Barometric pressure 743.6 mm.

	+	-
Visible Glow	6680	7100

P.D.	Galv. defl. in mm.		Shunt Factor		Current in 10^{-4} amp.	
	+	-	+	-	+	-
7500	90.0	70.0	110.9	110.9	0.310	0.241
8000	175.5	20.3	110.9	1109.0	0.605	0.700
9100	45.0	50.0	1109.0	1109.0	1.55	1.72
10000	77.0	88.5	1109.0	1109.0	2.65	3.05

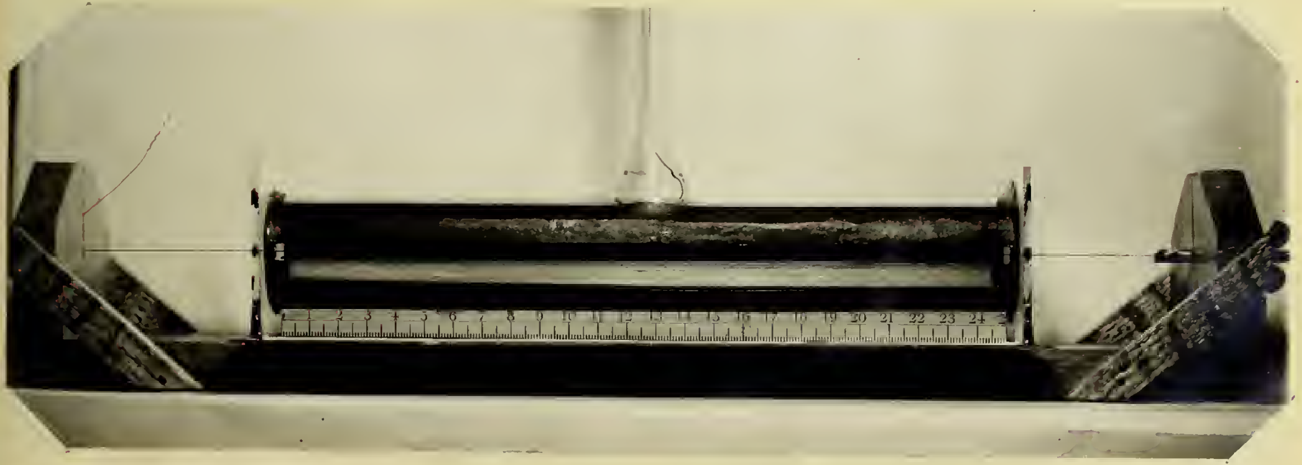


FIG.21

3/3/14

previously. Then various forms of discharge were produced and photographs taken of them. Table 25 contains data on the conditions for the different discharges and the photographs follow in the figures.

Series #1, Figs.22 and 23, was taken to give an idea of the development of the discontinuous discharge from a few intensely bright beads to a series of small brushes spaced with considerable regularity along the wire. For the lowest pressures the beads consist of a bright cylindrical core along the wire, which core is surrounded by a narrow dark space, enveloped in turn by a purple glow of relatively large diameter. For increasing pressures the central core contracts to a point and the discharge instead of surrounding the wire to form a bead, starts from this bright point and spreads out fan-like in a plane at right angles to the wire. For still higher pressures the fan seems to shut up and finally degenerates to a small brush. For all of the photographs in Series 1. except #36 and #37, the wire was not stretched tightly and therefore the regularity of spacing of the brushes is not very great. The two photographs mentioned were taken with the wire tightly stretched and the regularity of spacing is apparent. #10 shows the typical uniform positive glow. #12 shows the effect upon the brush discharge of inserting an arc in series with the tube.

Series #3, Fig.24., shows the evolution of the isolated brush form of negative discharge from a continuous glow. For a P.D. just above the critical value, the negative wire was enveloped by a more or less hazy continuous discharge. Keeping the pressure in the tube constant and raising the voltage slightly causes some of the glow to turn into brushes and with increasing voltage all of the glow is converted into the uniformly spaced form

of brush discharge. Sometimes conditions can be arranged so that the brushes appear one after another with apparently no change in the conditions.

Series #4, Fig.25., shows some typical discharges at higher pressures. #24 shows the appearance of the ordinary purple negative discharge at atmospheric pressure. The general messy character of the discharge is evident.

Series #5 was taken to find, if possible, some definite relation between the number of brushes and the P.D. for a given pressure in the tube. The increase of the number of brushes with the voltage and the regularity of spacing of the brushes is apparent. The photographs were taken at voltages for which the distribution of brushes was most regular. For the highest voltages, the brushes were in constant movement back and forth along a short path and to secure a good picture it was necessary to make the time of exposure quite short.

Fig.28 is the characteristic curve for the currents and voltages employed in Series 5. This graph shows the rate of increase of current with voltage to be very great at the highest voltages employed.

Fig.29 shows the number of brushes as a function of the P.D. In some of the photographs some of the brushes were seen to be smaller than the rest and for the plotting of the graph the estimated equivalent number of full-sized brushes was taken. Evidentally the number of brushes is some well-defined function of the P.D. Between the voltages at which the arrangement of brushes was most regular, there seemed to be a transition period in which there were many little brushes in addition to the larger ones. An increase of voltage would then produce a set of full-sized brushes.

TABLE 25.

Data on Photographs of Corona

#30 B. & S. Copper Wire. Diameter 0.26 mm., along axis of slit brass tube of internal diameter 3.5 cm., 25 cm. long Slit 0.6 cm. wide.

Small divisions of scale shown in photographs are millimeters.

Series No. 1

Pressure and P.D. Varied

Plate No.	Polarity of Wire	P.D.	Pressure in mm.	Current 10^{-4} amp.	No. of Brushes	Current per Brush 10^{-4} amp.
1	-	600	9.9	6.39	2	3.19
2	-	850	19.2	2.42	4	0.605
3	-	880	19.2	4.35	5	0.870
5	-	1200	34.3	1.83	5	0.366
7	-	1600	58.0	3.62	15	0.240
8	-	1920	75.7	2.24	13	0.172
9	-	2200	75.7	3.38	21	0.161
10	+	2350	75.7	1.12	-	---
11	-	3500	112.6	7.63	32	0.238
*12	-	3800	112.6	1.31	-	---
36	-	4940	213.2	4.54	32	0.142
37	-	1450	46.9	4.33	19	0.228

*Short arc in series.

Series No. 2

Pressure Constant Effect of Short Arc in Series

Plate No.	Polarity of wire	Arc	P.D.	Pressure in mm.	*Current 10^{-4} amp.
13	+	Out	4010	112.6	3.79
14	+	In	4100	112.6	2.17
15	-	Out	3950	112.6	4.65
16	-	In	4110	112.6	2.23

* For arc in, this only continuous component.

TABLE 25. continued

Series No. 3

Wire Negative Pressure Constant

Evolution of Isolated Brushes from Continuous Glow

Plate No.	P.D.	Pressure in mm.	Current 10^{-4} amp.	No. of Brushes
17	4210	261.8	0.722	2
18	4460	261.8	1.24	6
19	4750	261.8	1.89	11
20	5120	261.8	2.68	12

Series No. 4

Typical Discharges at Higher Pressures

Plate No.	Polarity of wire	Arc	P.D.	Pressure in mm.	Current 10^{-4} amp.
21	-	Out	5320	357.0	0.110
22	+	In	6080	357.0	0.200
23	-	Out	8500	737.6	0.134
24	-	Out	10160	737.6	0.362

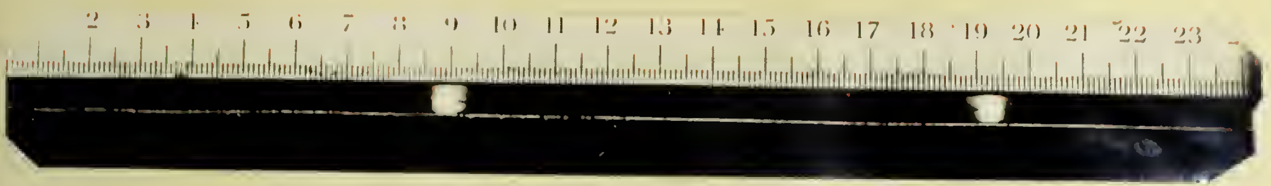
TABLE 25. continued

Series No. 5

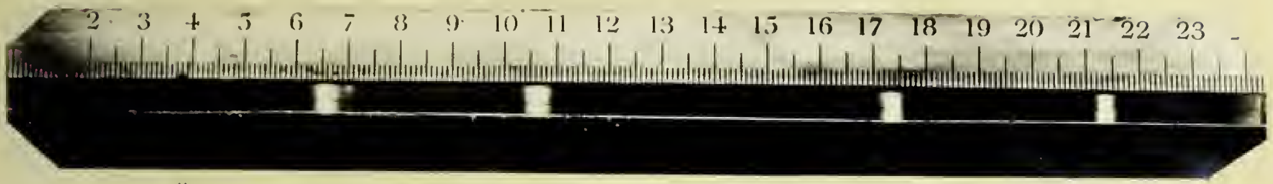
Wire Negative Pressure Constant

Plate No.	P.D.	Pressure in mm.	Current 10^{-4}amp.	No. of Brushes	Current per Brush 10^{-5} amp.
26	2500	119.3	0.327	11?	0.30
27	2700	119.3	0.826	16?	0.52
28	2800	119.3	1.03	17	0.606
29	2960	119.3	1.62	21	0.771
30	3160	119.3	2.23	22	1.01
31	3370	119.3	3.37	26	1.29
32	3350	119.3	4.65	30	1.55
33	3700	119.3	6.54	35	1.87
34	3870	119.3	10.0	42	2.38
25	3940	119.3	12.2	45	2.71
35	4020	119.3	16.2	47	3.38

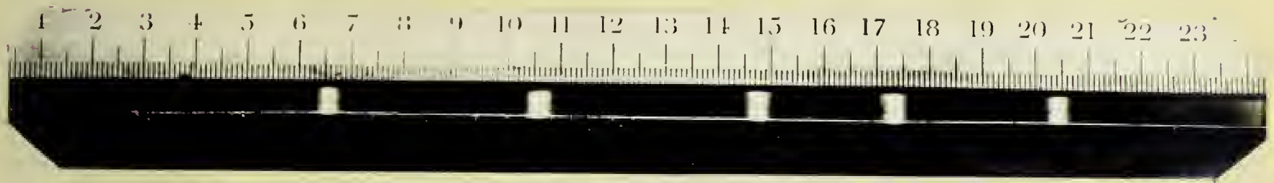
FIG.22.



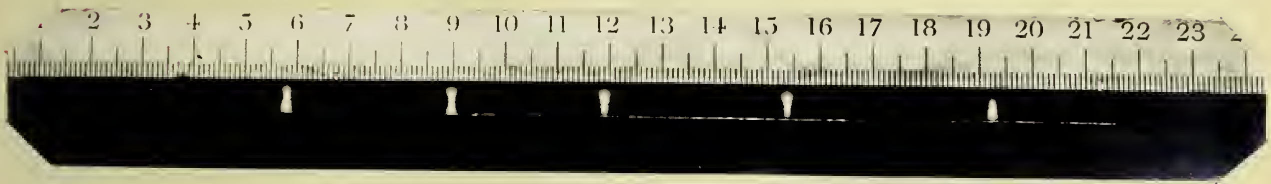
#1----negative----600 volts-----9.9 mm.



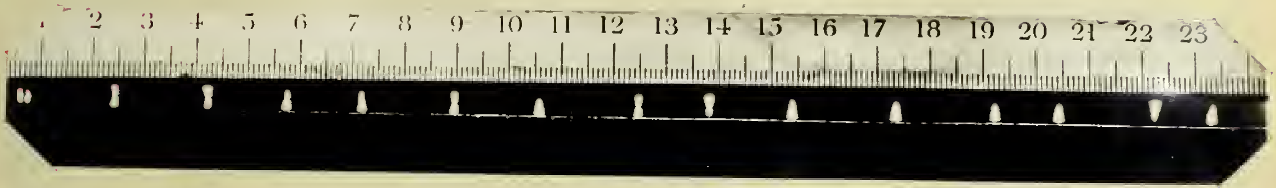
#2----negative----850 volts-----19.2 mm.



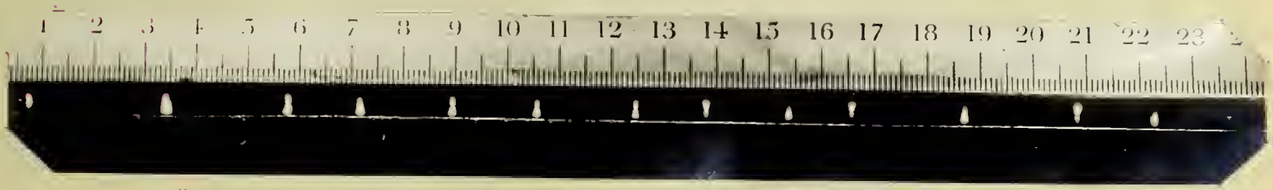
#3----negative----880 volts-----19.2 mm.



#5----negative---1200 volts-----34.3 mm.



#7----negative---1600 volts-----58.0 mm.

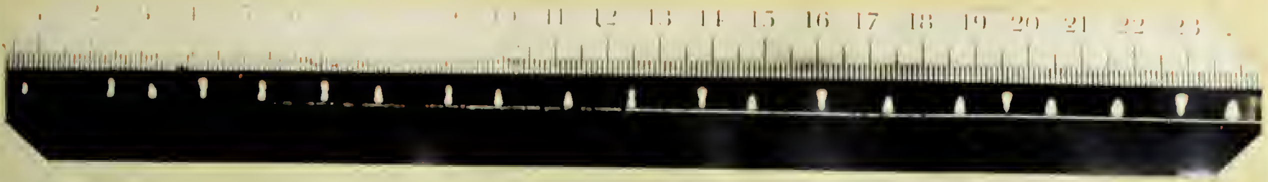


#8----negative---1920 volts-----75.7 mm.

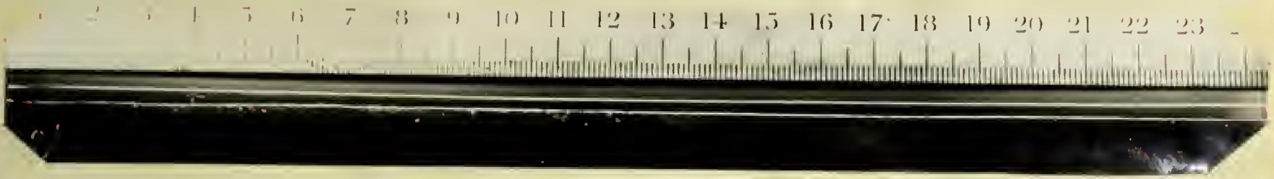
SERIES #1

Pressure and P.D. Varied.

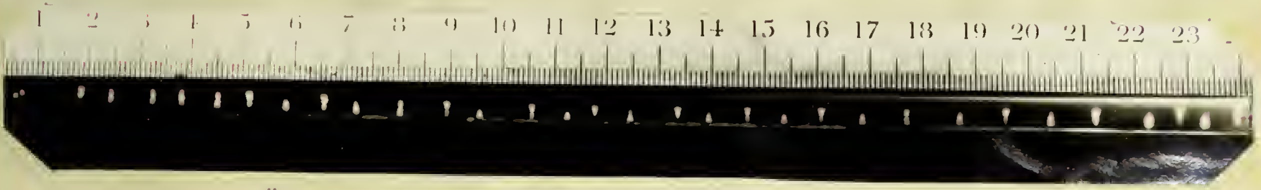
FIG.23.



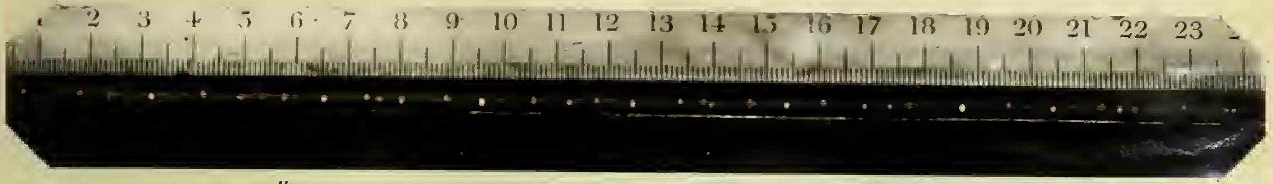
#9-----negative-----2200 volts-----75.7 mm.



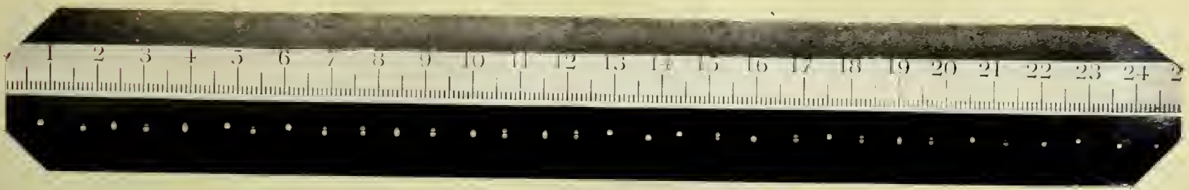
#10-----positive-----2350 volts-----75.7 mm.



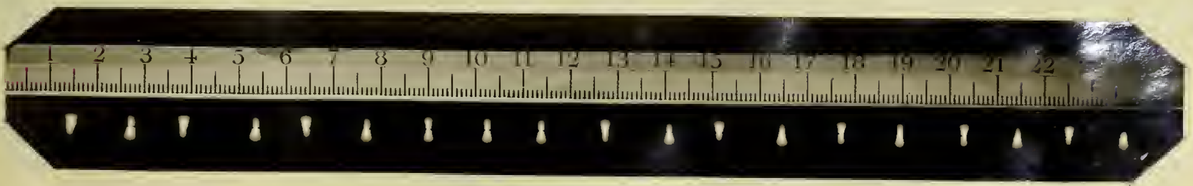
#11-----negative-----3500 volts----112.6 mm.



#12--negative,arc in series--3800 v.--112.6 mm.



#36-----negative-----4940 volts----213.2 mm.

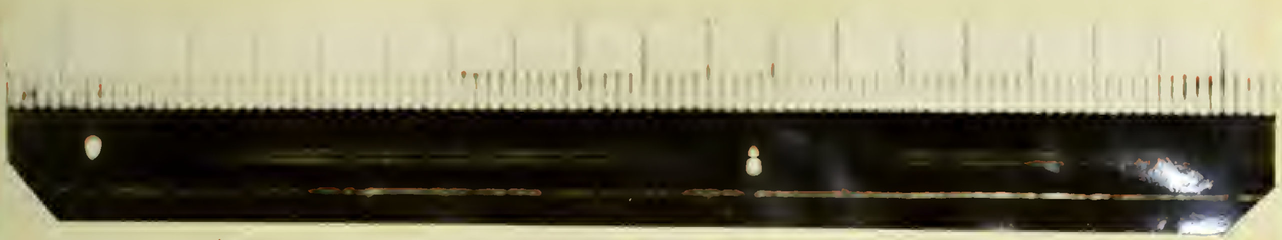


#37-----negative-----1450 volts-----46.9 mm.

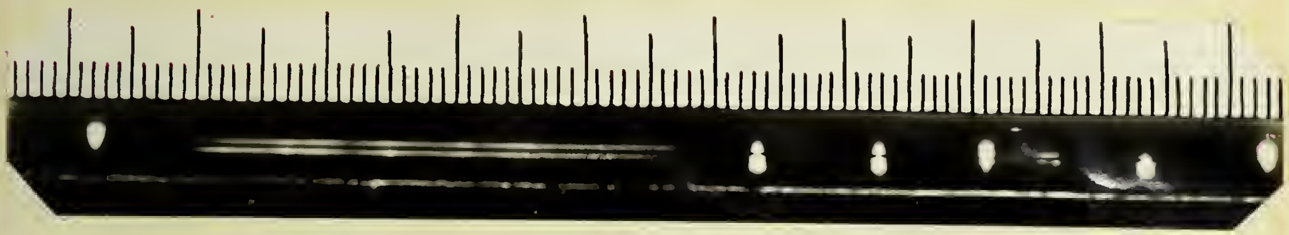
SERIES #1 (cont'd)

Pressure and P.D. Varied.

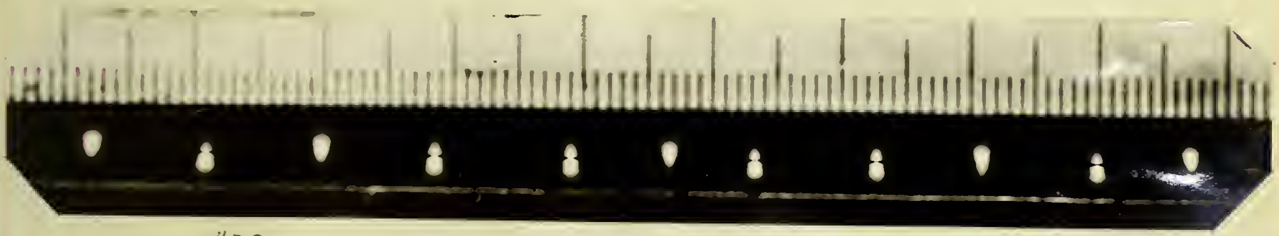
FIG.24.



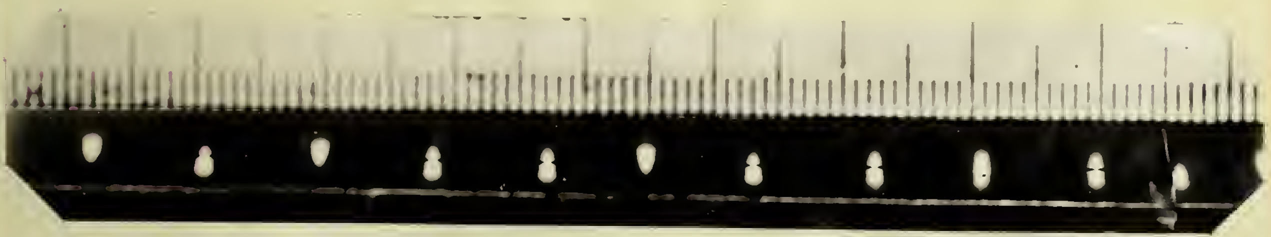
#17----negative----4210 volts----261.8 mm.



#18----negative----4460 volts----261.8 mm.



#19----negative----4750 volts----261.8 mm.

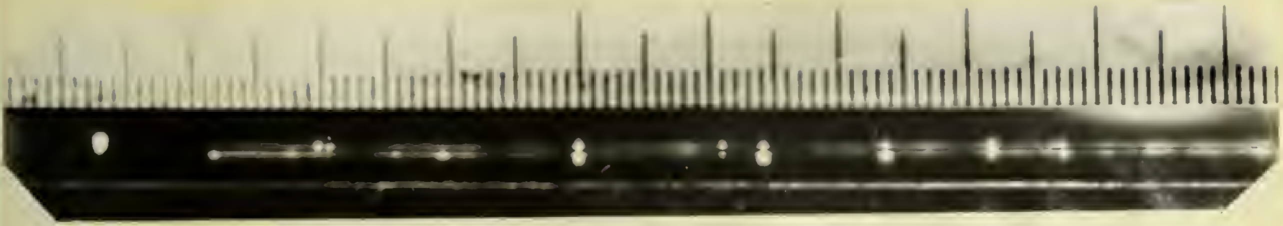


#20----negative----5120 volts----261.8 mm.

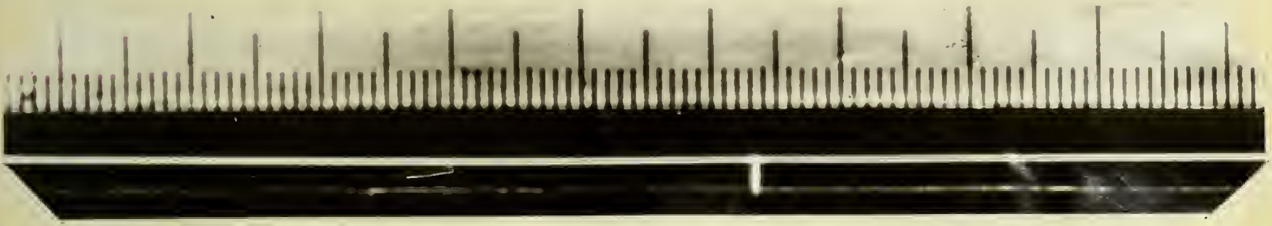
SERIES #3

Wire Negative. Pressure Constant.
Evolution of Isolated Brushes from Continuous Glow.

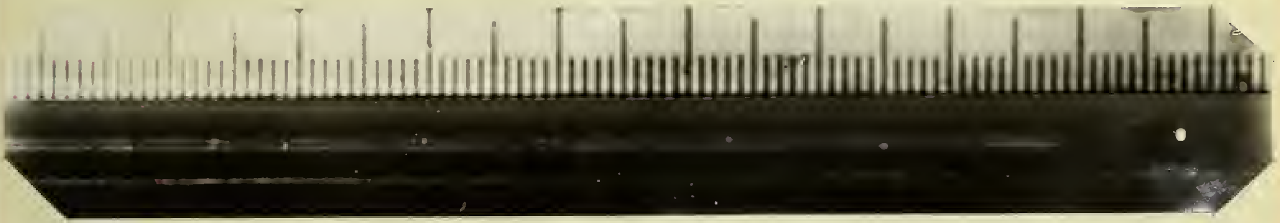
FIG.25.



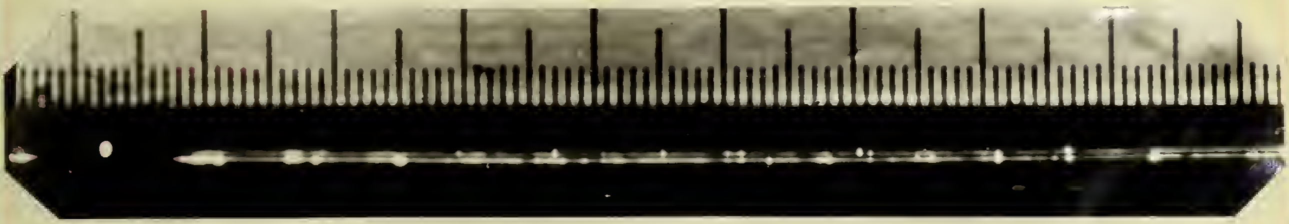
#21-----negative-----5320 volts-----357.0 mm.



#22--positive-arc in series-6080 v.-357.0 mm.



#23-----negative-----8500 volts-----737.6 mm.

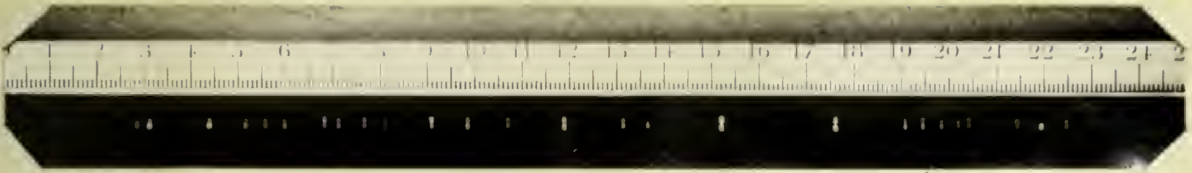


#24-----negative----10160 volts-----737.6 mm.
Typical negative discharge at atmos. press.

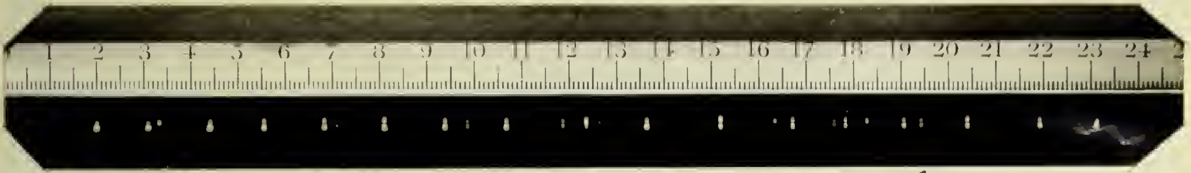
SERIES #4

Typical Discharges at Higher Pressures.

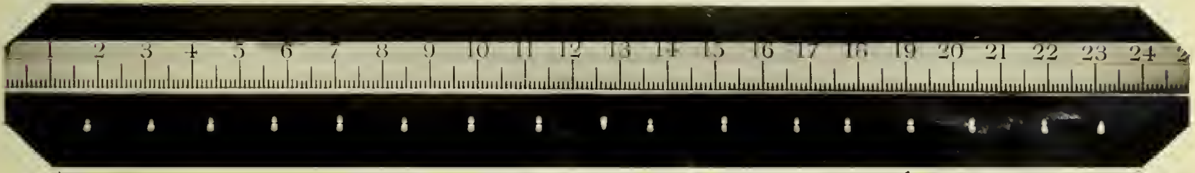
FIG.26.



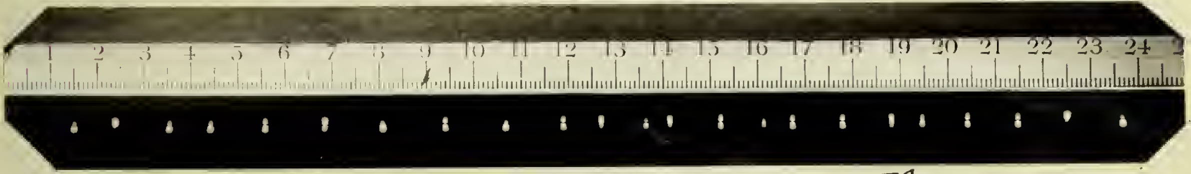
#26----2500 volts----0.327 x 10^{-4} amp.



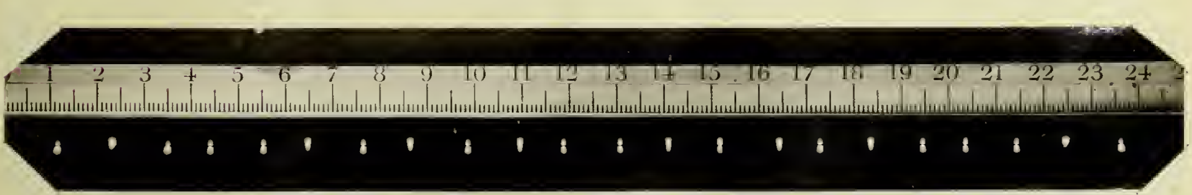
#27----2700 volts----0.826 x 10^{-4} amp.



#28----2800 volts----1.03 x 10^{-4} amp.



#29----2960 volts----1.62 x 10^{-4} amp.



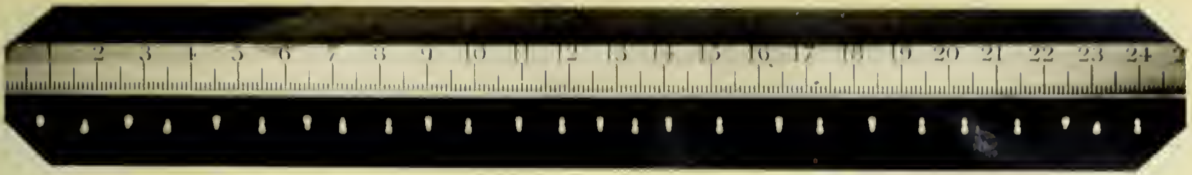
#30----3160 volts----2.23 x 10^{-4} amp.

SERIES #5

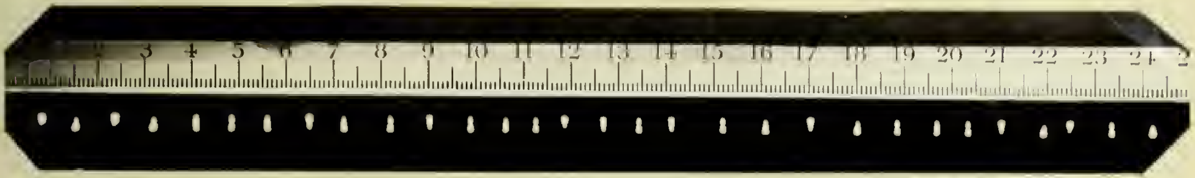
Wire Negative. Pressure Constant at 119.3 mm.

Showing Variation of the Number of Brushes with the P.D.

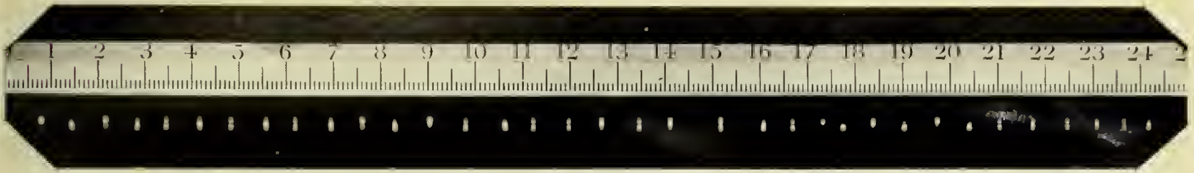
FIG.27.



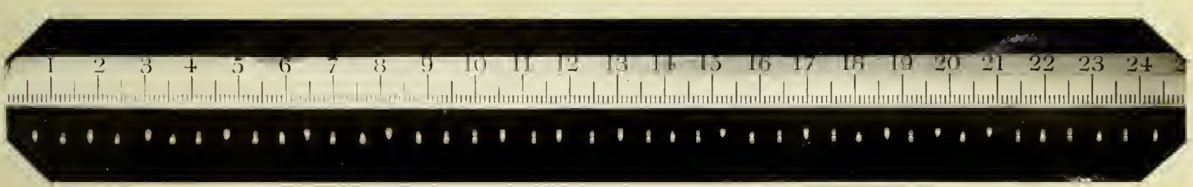
#31-----3370 volts-----3.37 x 10^{-4} amp.



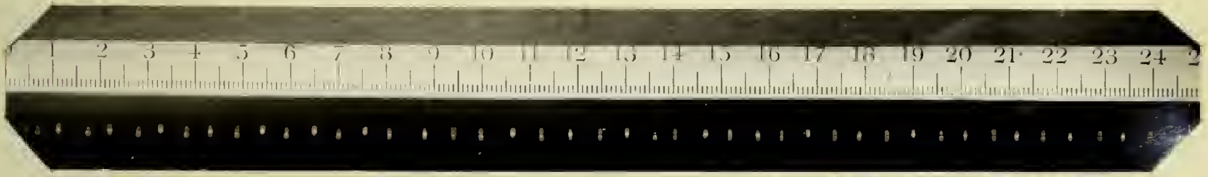
#32-----3550 volts-----4.65 x 10^{-4} amp.



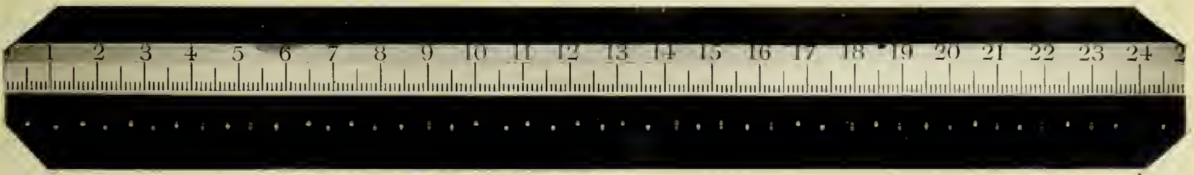
#33-----3700 volts-----6.54 x 10^{-4} amp.



#34-----3870 volts----10.0 x 10^{-4} amp.



#25-----3940 volts----12.2 x 10^{-4} amp.



#35-----4020 volts----16.2 x 10^{-4} amp.

SERIES #5 (cont'd)

Wire Negative. Pressure Constant at 119.6 mm.

FIG. 28.

#30 B. & S. COPPER WIRE ~ DIAMETER 0.26 MM.
IN
SLIT TUBE OF DIAMETER 3.50 CM., LENGTH 25.0 CM.
SLIT 0.60 CM. WIDE

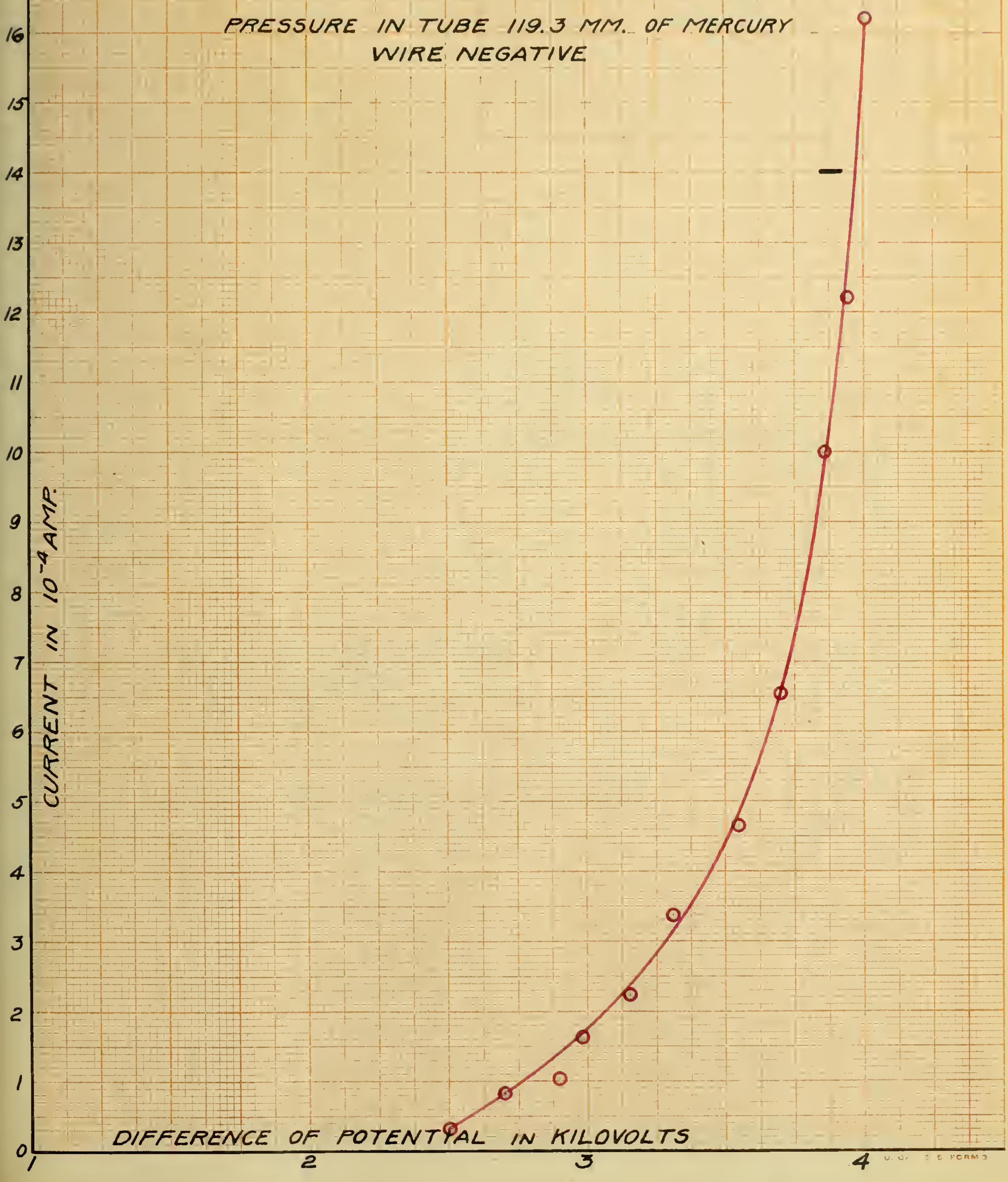
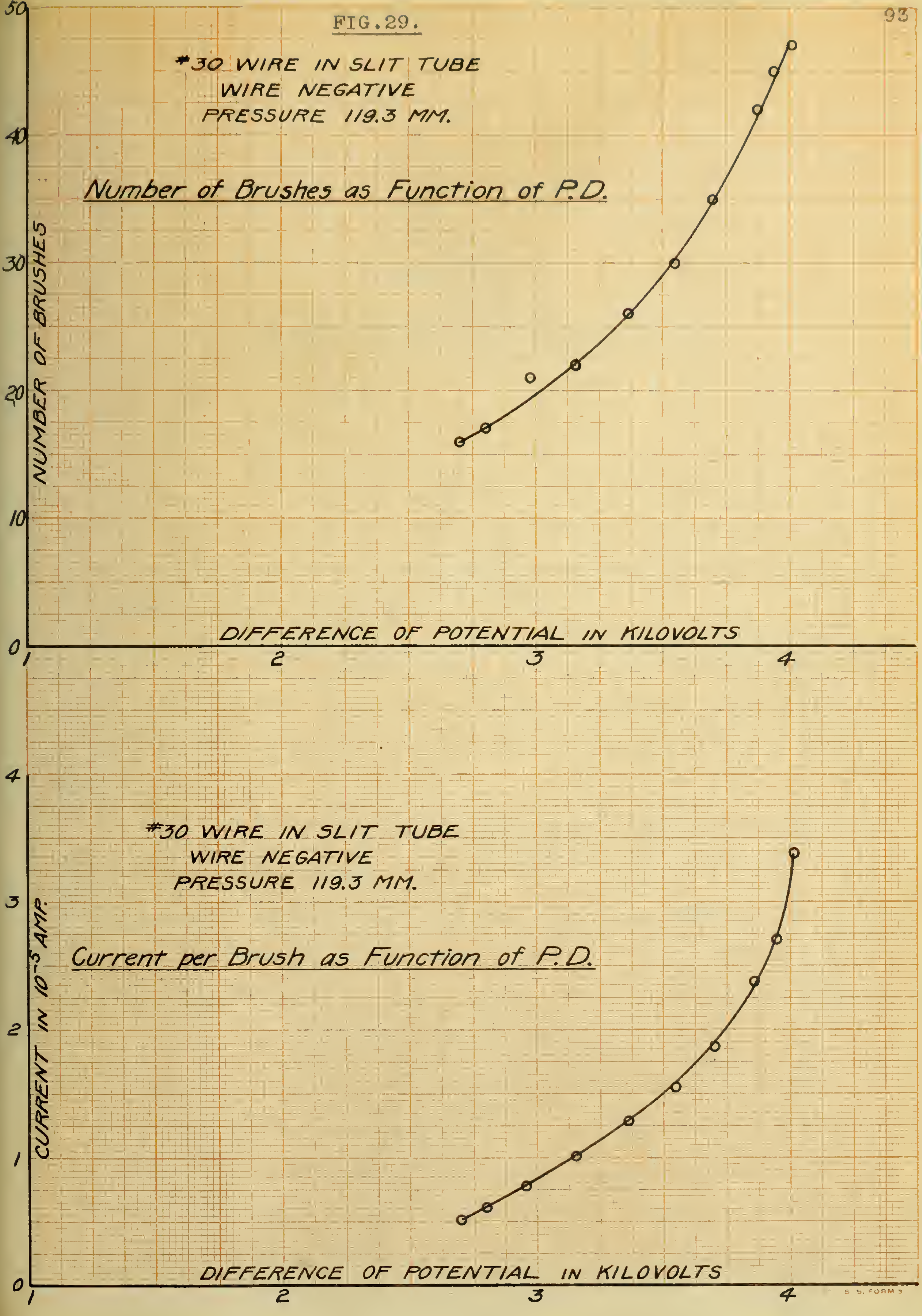


FIG.29.


*30 WIRE IN SLIT TUBE
WIRE NEGATIVE
PRESSURE 119.3 MM.
Number of Brushes as Function of P.D.
NUMBER OF BRUSHES
50
40
30
20
10
0
DIFFERENCE OF POTENTIAL IN KILOVOLTS
1
2
3
4
*30 WIRE IN SLIT TUBE
WIRE NEGATIVE
PRESSURE 119.3 MM.
Current per Brush as Function of P.D.
CURRENT IN 10^{-5} AMP.
4
3
2
1
0
DIFFERENCE OF POTENTIAL IN KILOVOLTS
1
2
3
4
S. S. FORM 3

--Chapter VIII--

Effect of Short Arc upon Discharges

Series #2, Fig.30., shows the effect of a short arc in series with the tube upon the character of the positive and negative discharges for a constant pressure in the tube and an approximately constant voltage..

The typical quiet bluish positive discharge shown in #13 is changed to #14, which is more brilliant, of a purple tinge and greater in diameter. In addition its boundaries seem more ragged.

The typical discontinuous negative discharge has its character changed most markedly by the introduction of the arc. #16 shows the changed discharge; it seems to be made up of two effects superimposed upon each other. The arc evidently sets up high frequency oscillations in the circuit and an alternating effect is superimposed on the direct current phenomenon. To test whether this theory was correct, the following experiment was tried:-

A 2 mf. condenser was connected in parallel with the tube and with the arc in circuit a P.D. was impressed upon the tube of a value high enough to give corona. The appearance was then as though there were no arc in the circuit. The high frequency

component of the current prefers rather to take the path through the condenser than to go across the air-gap.

It took an appreciable time for the condenser to become fully charged and during this time occurred the evolution of the brush discharge from the continuous glow in the manner mentioned above, except that the time of the process was prolonged.

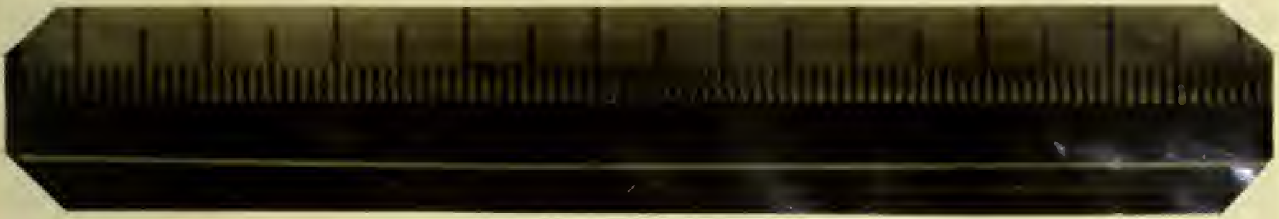
Upon disconnecting the charged apparatus from the source of potential, the discharge through the tube persisted for some seconds due to the discharge of the condenser thru it. As the voltage of the condenser fell, the number of the brushes became fewer and their brightness diminished until they vanished. During this discharge, the brushes maintained quite a regular arrangement.

The production of the discontinuous negative discharge by the discharge of a condenser is a good argument that the discontinuous discharge is essentially a continuous potential phenomenon. It is easy to calculate from an assumption of fair values for the electrical constants of the circuit that the discharge of the condenser must be of the continuous type and hence no alternating effect is possible.

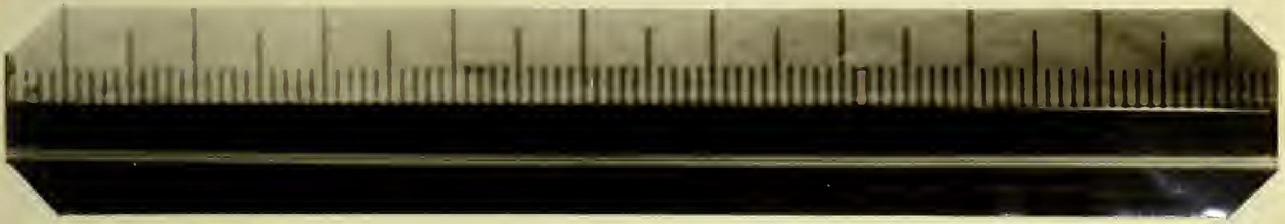
This series of experiments with the arc in series illustrates very clearly the great difference between positive and negative and furnishes a good example of the continuous discharge of a condenser.

It should be noted in connection with the values of current given for discharges with an arc in series that these give only the continuous components of the current.

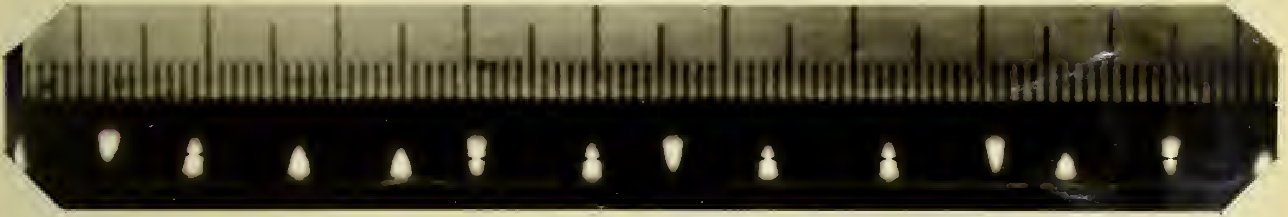
FIG.30.



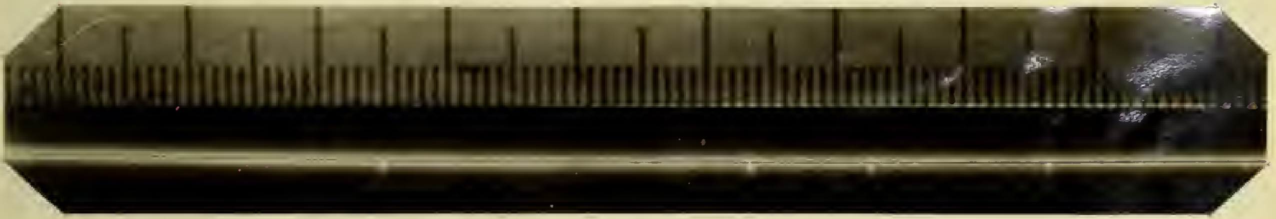
#13---positive---no arc---4010 volts---112.6 mm.



#14---positive----arc----4100 volts---112.6 mm.



#15---negative---no arc---3950 volts---112.6 mm.



#16---negative---arc----4110 volts----112.6 mm.

SERIES #2

Pressure Constant: Effect of Short Arc in Series.

--Chapter IX--

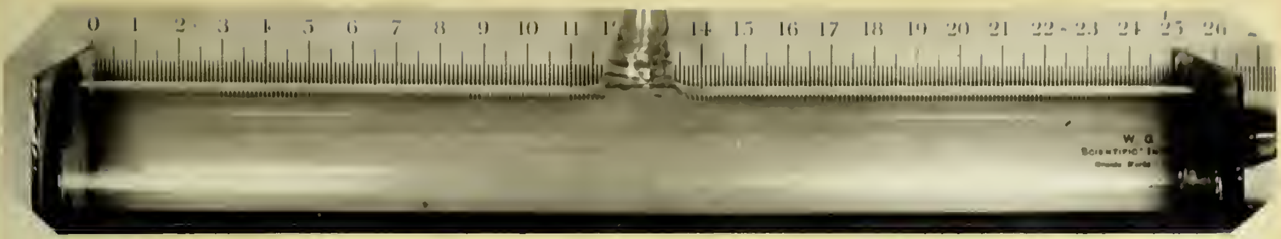
Corona between Parallel Wires

Section 1: Phenomena at Reduced Pressures.

Two #34 wires, 0.167 mm. in diameter, were arranged parallel and two centimeters apart inside of a glass tube as shown in Fig.31. and the photographs in Fig.32. were taken of the discharge between them at reduced pressures. The three lower photographs show the typical isolated brush discharge on the negative wire with corresponding luminous sections of the positive wire. The negative brushes had a brilliant nucleus with a fainter glow spreading out from it. For lower pressures than those for which the photographs were taken, the discharge became more brilliant; the brushes spread farther apart and increased in size. Each section of positive glow was usually of uniform brilliancy. But for comparatively low pressures and high voltage, these positive sections became somewhat discontinuous, bright spots being mixed in with the uniform glow.

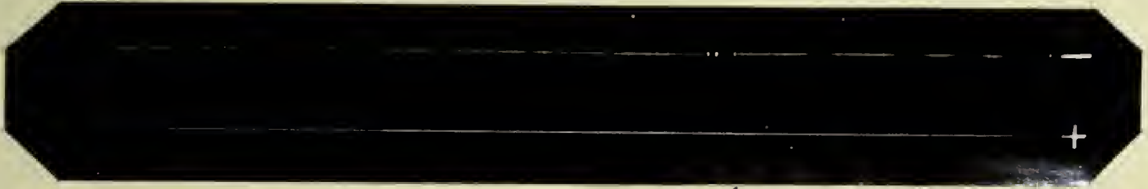
The introduction of a short arc in series made a marked change in the nature of the discharge. Both wires were more or less completely covered with a nearly uniform glow and there was no longer any marked difference between positive and negative. The brilliancy of the discharge depended upon the fatness of the arc. With the arc in series, low pressure and a relatively high voltage,

FIG.32.

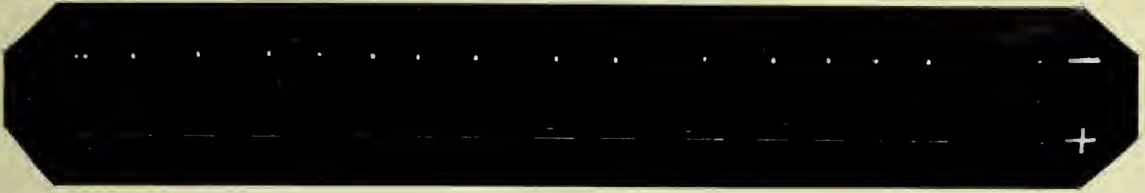


Apparatus Used. #34 Copper Wires, 0.167 mm. diam.,2 cm. apart.

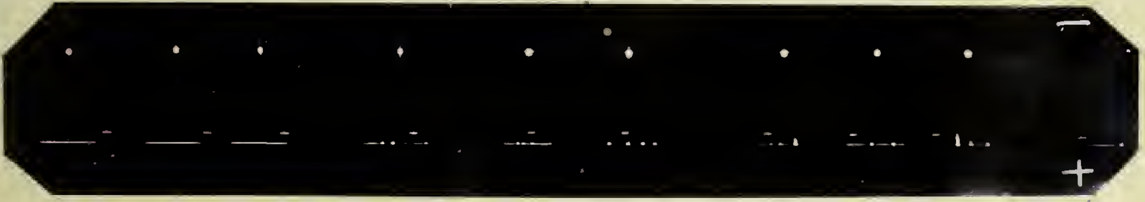
Arc in Series--8000 volts--1.80 x 10^{-4} amp.---312.2 mm.



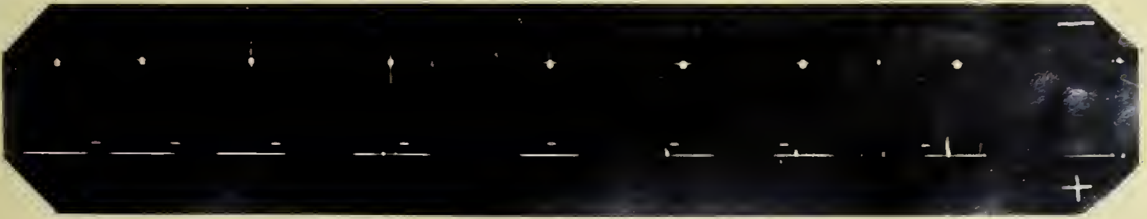
Arc in Series--8000 volts--1.14 x 10^{-4} amp---312.2 mm.



No Arc---------8000 volts--2.35 x 10^{-4} amp.---312.2 mm.



No Arc---------8700 volts---------------------450.0 mm.



No Arc---------8400 volts------------------450.0 mm.

SERIES #6

Corona between Parallel Wires at Reduced Pressures.

the discharge between the wires resembled a sheet of luminous rain. An intermediate effect had bluish streamers between the wires.

It should be remarked that the values of current given for the cases where an arc was used are only the continuous components of the current.

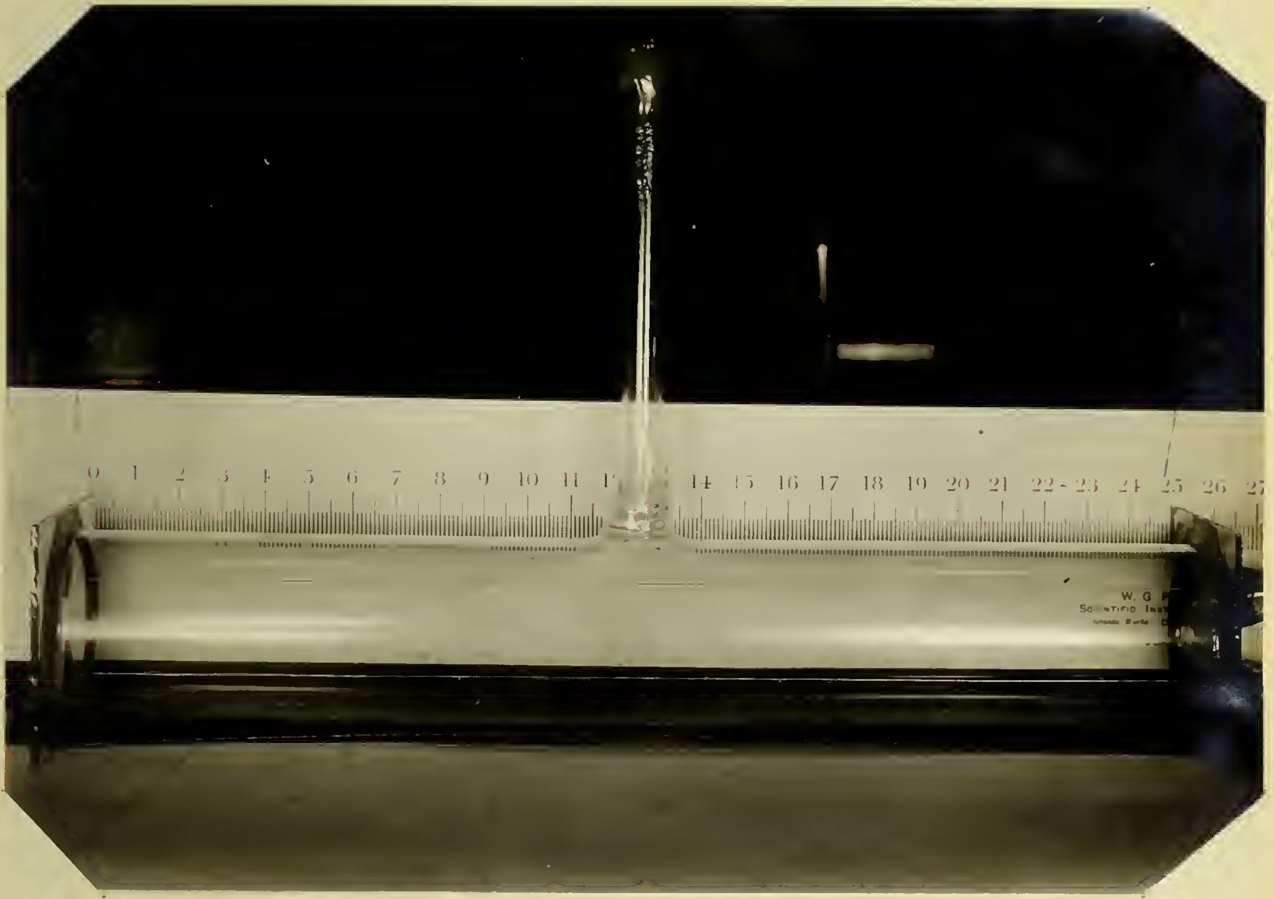


FIG.31

Section 2: Phenomena at Atmospheric Pressures.

Two #36 wires were stretched over hard rubber bridges so as to be parallel and three centimeters apart and a characteristic test was obtained for the discharge between them. The dimensions of the wires, the atmospheric conditions and the data for a characteristic curve are given in Table 26. A sudden increase of the deflection of the galvanometer marked the critical voltage as in the case of former tests with wires in a cylindrical field.

TABLE 26.

Two Parallel #36 Wires - 0.135 mm. diam.

36.2 cm. long and 3.0 cm. apart

Temperature	26.5
Relative Humidity	43.0%
Barometric Pressure	749.0

P.D.	Deflection in mm.	Shunt Factor	Current in 10^{-4} amp.
6000	0.3	1.0	0.000015
6400	0.5	1.0	0.000025
6500	Critical Voltage		
7000	125.0	1.0	0.00634
8000	37.0	12.832	0.0241
9000	75.0	12.832	0.0488
10000	30.0	128.32	0.195
12000	198.0	128.32	1.29
14000	49.0	1283.2	3.19

F = 5.07 x 10^{-9} amp. per mm. deflection

5/6/14

It was noted in this test that there was a considerable current flow between the wires before there was any indication of a glow. At 10000 volts a flickering glow along the positive wire gave the first indication of a general glow.

When the visible discharge was fairly started, it took the form of a uniform continuous glow along the positive wire and a fairly regular arrangement of brushes along the negative wire. This discharge was examined on a day when the humidity was considerably greater and it was noticed that negative discharge had lost all appearance of a regular distribution and there was more of a continuous glow effect.

It was noticed that the negative wire bowed in toward the positive and that the positive bowed away from the negative. This effect was noticed in one of the preliminary experiments with an influence machine.

When the wires were purposely made rather slack in order to intensify the effect it was found that the positive wire vibrated strongly with a circular motion and that the negative was motionless. If the polarity of the wires was reversed, the phenomenon reversed also and it was still the positive wire which vibrated.

Section 3. Exploration of Field between Parallel Wires.

A glass tube with a platinum contact wire projecting axially from its tip was fixed into a wood block in such a manner that when the block was moved across a board beneath and parallel to the plane of the wires, the platinum contact point moved in the plane of the wires. By means of a scale fixed across the board perpendicular to the direction of the wires it was possible to set

the contact point at any desired position between the wires. When the ground terminal of one of the electrostatic voltmeters was connected to the grounded negative wire and the high tension terminal was connected to the contact point it was found that the voltmeter deflected when there was a current flow between the wires and the contact point was in the neighborhood of the wires. So long as there was no current flow between the wires there was no deflection.

Table 27 gives the results of an exploration of the field for differences of potential of 8000, 10000, and 12000 volts between the wires.

Fig.33 shows the curves for field distribution as plotted from the data of Table 27 and also the distribution of the electrostatic field between the wires as calculated from the formula for the electrostatic field on a line between the axes of parallel wires. If P denote the point where the potential is desired, A and B the inverse points of the circular sections of the wires and q represents the charge per unit length of one wire, the potential V at the point is given by

$$V = - 2q \log (AP/BP)$$

Sufficient accuracy was obtained for the purpose in hand by taking the inverse points as at the centers of the wires.

An examination of the curves for the actual distribution of the field discloses the fact that there are large anode and cathode falls of potential, the anode fall of potential being the greater for the two lower potential differences. For these also the actual field departs widely from the electrostatic. For the 12000 curves the actual and electrostatic fields become more alike.

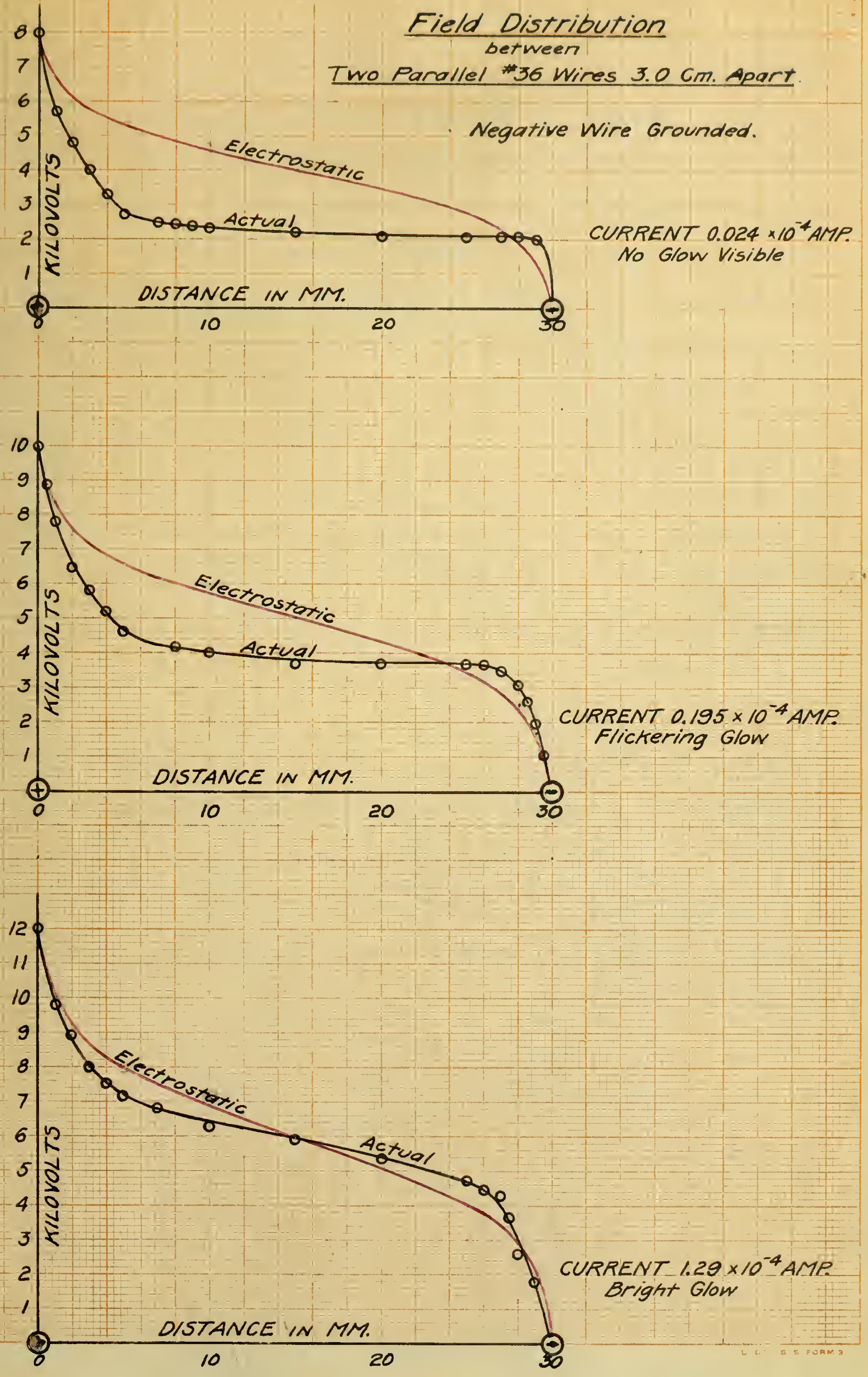
The field is distorted through ionization, because the positive are driven toward the negative wire and form a layer of positive electricity round about the negative wire. Hence there results a very large fall of potential around this wire. Around the positive wire there is an accumulation of negative electricity and hence there is a fall of potential here also. But the positive and negative ions are of different size and mobility and therefore the distortion of the field about the positive wire is different from that around the negative wire.

TABLE 27.

Distribution of Field Between Two Parallel #36 Wires 36.2 cm. Long and 3.0 cm. Apart for Differences of Potential Between Wires of 8000, 10000 and 12000 Volts

mm. Distance from Neg. Wire	8000	10000	12000	mm. Distance from Neg. Wire	8000	10000	12000
0.	0	0	0	0.	0	0	0
0.5	unsteady	1060	---	20.0	2340	4000	6260
1.0	2050	2000	1800	21.0	2400	--	--
1.5	2130	2600	2110	22.0	2430	4200	--
2.0	2100	3100	2600	23.0	2460	--	6800
2.5	--	--	3650	25.0	2700	4620	7200
3.0	2100	3400	4290	26.0	3300	5200	7540
4.0	--	3660	4460	27.0	4000	5800	8000
5.0	2070	3680	4680	27.5	--	--	--
7.0	--	--	--	28.0	4800	6500	8960
8.0	--	--	--	28.5	--	--	--
9.0	--	--	--	29.0	5700	7800	9800
10.0	2090	3700	5380	29.5	--	8900	--
15.0	2100	3700	5900	30.0	8000	10000	12000

FIG.33.



Field Distribution
between
Two Parallel #36 Wires 3.0 Cm. Apart

Negative Wire Grounded.

VITA

Stanley P. Farwell was born at Chicago, Illinois, September 29, 1883. He received his early training in the public schools of Chicago. His secondary training was received in the Chicago Manual Training School, from which he graduated in 1900. After spending four years in the shops and engineering inspection department of the Western Electric Company, Chicago, he entered the University of Illinois in 1904, graduating in 1907 with the degree of Bachelor of Science in Electrical Engineering. The year 1907-08 was spent in central station work. In 1908 he went to the Central University of Kentucky as Assistant Professor of Electrical Engineering, remaining there until 1910 when he went back to Illinois as Instructor in Theoretical and Applied Mechanics.

For work done in absentia he received the M.S. degree from Illinois in 1910. The rest of his graduate work was done while teaching mechanics and while holding a fellowship in electrical engineering during the year 1913-14.

The Physical Review now has in press a paper of his entitled "Some Brush Discharge Phenomena Produced by Continuous Potentials".

TABLES

Number Page

1 Wire Diameter 0.027 mm. 27

2 Wire Diameter 0.037 mm. 28

3 Wire Diameter 0.046 mm. 30

4 Wire Diameter 0.052 mm. 32

5 Wire Diameter 0.077 mm. 34

6 Wire Diameter 0.077 mm. 36

7 Wire Diameter 0.135 mm. 37

8 Wire Diameter 0.24 mm. 39

9 Wire Diameter 0.26 mm. 41

10 Wire Diameter 0.41 mm. 43

11 Wire Diameter 0.65 mm. 45

12 Wire Diameter 0.77 mm. 46

13 Tests Wire Diameter 1.02 mm. and 1.28 mm. 47

14 Glow Voltage and Radius 49

15 Critical Voltage and Pressure 0.41 mm. Wire 52

16 Temperature and Current 0.135 mm. Wire 72

17 Effect of Pressure - 0.41 mm. Wire 54

18 Effect of Pressure – 0.135 mm. Wire 57

19 Characteristic Test, 760 mm. for 0.052 mm. Wire 60

20 Condition of Air and Current Test 65

21 Effect of Pressure - 0.077 mm. Wire 62

22 Effect of Moisture - 0.077 mm. Wire 67

23 Pressure Due to Ionization 77

24 Characteristic Curve - 0.26 mm. Wire 80

25 Data on Photographs of Corona 83

26 Characteristic Test - Parallel Wires 100

27 Distribution of Field Between Parallel Wires 104

Page

Chapter VII Discontinuous Brush Discharge 79

Chapter VIII Effect of Short Arc Upon Discharges 94

Chapter IX Corona between Parallel Wires 97

Section 1 Phenomena at Reduced Pressures 97

Section 2 Phenomena at Atmospheric Pressures 99

Section 3 Exploration of Field 101

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